Medical Lib.

MAR 10 1922

JOURNAL OF ANATOMY

ORIGINALLY THE JOURNAL OF ANATOMY AND PHYSIOLOGY

CONDUCTED ON BEHALF OF THE ANATOMICAL SOCIETY OF GREAT BRITAIN AND IRELAND BY

PROFESSOR EDWARD FAWCETT — UNIVERSITY OF BRISTOL
PROFESSOR J. P. HILL — UNIVERSITY OF LONDON
PROFESSOR ARTHUR ROBINSON — UNIVERSITY OF EDINBURGH
PROFESSOR E. BARCLAY-SMITH — UNIVERSITY OF LONDON
PROFESSOR SIR ARTHUR KEITH — ROYAL COLLEGE OF SURGEONS

LINCOLN'S-INN-FIELDS, LONDON, W.C. 2

VOLUME LVI

PART II

JANUARY 1922

Entered at New York Post Office as Second Class Matter

(*All Rights reserved*)

CAMBRIDGE UNIVERSITY PRESS
C. F. CLAY, MANAGER
LONDON: FETTER LANE, E.C. 4
also
H. K. LEWIS & CO., LTD., 136, GOWER STREET, LONDON, W.C. 1
WHELDON AND WESLEY, LTD., 28, ESSEX STREET, LONDON, W.C. 2
CHICAGO: THE UNIVERSITY OF CHICAGO PRESS
(AGENTS FOR THE UNITED STATES AND CANADA)
BOMBAY, CALCUTTA, MADRAS: MACMILLAN & CO., LTD.
TOKYO: THE MARUZEN-KABUSHIKI-KAISHA

Price Ten Shillings net

Cambridge University Press

A CASE OF EARLY HUMAN OVARIAN PREGNANCY

By JOHN I. HUNTER, M.B., Ch.M.

Associate Professor of Anatomy, University of Sydney.

The present paper comprises a complete description of a specimen of primary ovarian pregnancy, of which I have already published a preliminary account ('21). The specimen was presented to me by Professor J. T. Wilson, who had received it from the Royal Prince Alfred Hospital, Sydney, diagnosed as a case of primary ovarian pregnancy. I desire to express my great indebtedness to Professor Wilson for the opportunity he has given me to describe this interesting specimen. My investigations confirm the original diagnosis. They also demonstrate, as the clinical records of the case indicate, that the pregnancy is at a very early stage of development. This fact renders the specimen of considerable value and justifies the present detailed description because it helps to throw light upon the process of imbedding and the phenomena occurring in the early stages of primary ovarian pregnancy which are still imperfectly known (cf. Ray '21).

The specimen appears in the embryological collection of the Anatomy Department, Sydney University, under the catalogue number H 153, and it will be referred to throughout this account under this designation.

HISTORY OF THE CASE

The patient was under the care of Mr Joseph Foreman, Honorary Gynaecologist of the Royal Prince Alfred Hospital, who directed that the ovary removed at operation should be examined for ovarian pregnancy.

The patient (G.R. aet. 37) on admission on 1.7.14, complained of pain in the hypogastrium of 12 hours' duration. She had experienced a similar attack seven days previously in which the pain was accompanied by vomiting, rigor and perspiration. Her last menstrual period had appeared 22 days previously (9.6.14). Her periods were quite regular of the 28 day type, and consisted of a scanty flow of 3 days' duration. The patient, who had been married five years, had two children; the first was four years of age, the second two and a half years. There had been no miscarriages. On 3.7.14 four days before the next period was due, an operation for ectopic pregnancy was performed. The abdomen was opened in the median line and clotted blood was found in the pelvic peritoneal cavity. The right ovary appeared to be a mass of blood clot, and was deemed necessary to remove. The tubes were apparently normal. The mesovarium was crushed by an angioclast and the free tissue was removed with a scalpel.

The outstanding feature of this account is the regular menstrual history. Operation was performed four days before the time of commencement of the

menstrual period which, in all probability, would have been missed. In this respect the history resembles that of the cases reported by Lea ('10) and Chiene ('13). In neither of the above-mentioned cases, however, were embryonic structures recovered and exact comparison with H 153 in which an embryonic papilla was found within an intact chorionic vesicle, is impossible. The chorionic vesicle of H 153 was greatly compressed. Its internal dimensions were 10 × 4·7 mm. and the villi varied from 2–4 mm. in length. Histological examination of the sections obtained revealed a damaged embryonic papilla. The amniotic sac was found to be collapsed and ruptured. Blood from the intervillous space had apparently infiltrated into the embryonic papilla and invaded the yolk sac. The distorted papilla measures approximately 3·5 mm. in length (fig. 7). No details of embryonic structure can be ascertained. The abdominal stalk and the wall of the yolk sac contain blood vessels within which nucleated red blood corpuscles may be seen. The general features indicate that the stage of development approximated to, but was probably earlier than, that of Graf von Spee's embryo "Gle."

H 153 greatly resembles the ovarian pregnancy described by Bryce, Teacher and Kerr ('08). In this case there was a history of seven weeks' amenorrhoea. The chorionic vesicle measured approximately the same as H 153 and the villi were 2–3 mm. in length. There was a fragmentary papilla, the general characters of which resembled the "Gle" embryo. The dimensions indicate that the stage of development is approximately the same as in H 153.

It seems probable that H 153 is the result of fertilisation after the last menstrual period and if so the duration of gestation would be less than 20 days. However, as in Bryce, Teacher and Kerr's specimen retardation of the growth of the vesicle and embryo has probably occurred on account of the abnormal environment, or differentiation may have ceased after the first attack of intra-peritoneal haemorrhage, so that the condition of the embryonic structures is not a true guide of the exact time of duration of gestation.

NAKED EYE DESCRIPTION OF THE SPECIMEN

The specimen removed at operation had been divided longitudinally and consequently both external and cut surfaces were presented for inspection. It consisted of an ovary (4 × 1·5 cms.) from the surface of which, in proximity to one pole, there projected a dark haemorrhagic mass of rounded contour measuring 3 cms. supero-inferiorly and 2 cms. antero-posteriorly (figs. 1 and 2).

This mass rested upon the ovary for the distance of 2·5 cms. In its neighbourhood the ovary contained a corpus luteum of pregnancy measuring 14 × 8 mm. The opposite pole of the ovary was occupied by a large atresic follicle. In one situation a mass of blood projected from the otherwise smooth surface of the haemorrhagic swelling; the smoothness of the surface of the swelling was due to the presence of an investing fibrous capsule which could be traced into continuity with the ovarian stroma. At the point of junction it attained its maximum thickness (1 mm.). It became extremely thin upon the

surface of the haemorrhagic swelling and was apparently ruptured where the extravasation of blood was still represented by the projection of blood clot. The original cut had passed through the chorionic vesicle. In either

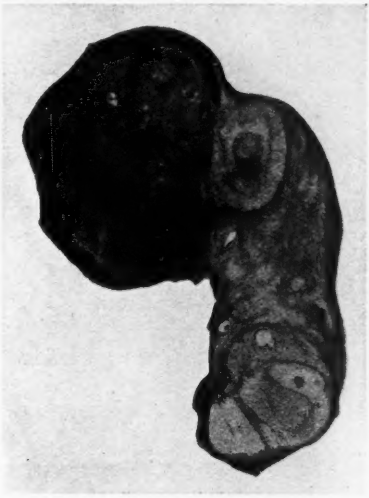


Fig. 1. Photograph of the ovary and the contained haemorrhagic swelling ($\times 1\frac{1}{3}$).

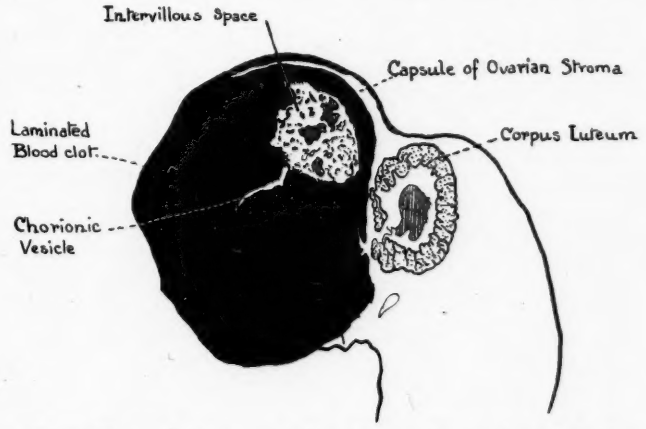


Fig. 2. Diagrammatic representation of the specimen as shown in fig. 1.

portion of the specimen this structure could be seen lying excentrically in the haemorrhagic swelling. An examination of the blood clot in the vicinity of the chorionic vesicle revealed the presence of villi in section. Also several branching villi were seen lying free in the crumbled blood clot. The villi could

be traced towards the wall of the chorionic vesicle. The interior of the vesicle was comparatively smooth, but at this stage (infiltration with celloidin was already in progress) no embryonic papilla was detected.

The evidence so far obtained is sufficient to establish H 153 as a genuine case of primary ovarian pregnancy.

THE CRITERIA OF PRIMARY OVARIAN PREGNANCY WITH REFERENCE TO THE FULFILMENT OF THE REQUIREMENTS BY H153

The arrival of the definite diagnosis of primary ovarian pregnancy is greatly facilitated by the early stage of development of H 153. As Norris ('09) states, "it is much easier to make a positive diagnosis of primary ovarian pregnancy prior to the sixth or eighth week, than it is later after the gestation sac has grown to such proportions as to change its relation to the surrounding parts." Freund and Thomé ('06), Webster ('04), Young and Rhea ('11) and Caturani ('14) have also stressed this fact.

It is necessary to exclude the following conditions which may closely simulate cases of primary ovarian pregnancy:

(*a*) Haematoma of the ovary due to a bleeding corpus luteum.

(*b*) Pregnancy in an accessory tube or in a diverticulum from the tube (cf. Webster, '02).

(*c*) Implantation upon the fimbria ovarica; or upon an accessory fimbria which may become detached from the tube; or upon the fimbriated extremity of the tube.

(*d*) A ruptured tubal pregnancy in the intraligamentous position.

Until full and careful histological descriptions were available of early cases difficulty was experienced in ruling out the existence of all these conditions. In 1898, in his Ingleby Lectures, J. W. Taylor states that "early rupture of a tube from a pregnancy of two, five or six weeks standing is a special phenomenon of extra-uterine pregnancy which has as yet not received the recognition it deserves." Now early operative treatment for ectopic pregnancy provides the best opportunities for securing such specimens as H 153, and in the absence of early stages the scepticism of Lawson Tait and Bland Sutton as to the existence of genuine cases of primary ovarian pregnancy was justifiable. Lawson Tait ('88) asserted that all so-called cases were primarily tubal. In an editorial upon the subject in 1900 the British Medical Journal declared that Webster, P. W. Taylor and Bland Sutton had adduced evidence which tended to confirm this opinion. Bland Sutton ('96) had stated that "ovarian dermoids and calcified foetuses from tubal ruptures into the broad ligament have been mistaken for primary ovarian pregnancy." In discussing Croft's fatal case (Croft, '00) in which a four months' foetus was removed and in which the ovary could not be found on the side of the tumour Bland Sutton reiterated these views. He stated that Croft's case was too far advanced to discuss dogmatically, but he would only be convinced of the possibility of the occurrence of

primary ovarian pregnancy, if he were shown "an early embryo and its membranes contained in a sac within the ovary." He was convinced of the genuineness of Van Tussenbroek's classical specimen in 1901. After having made a special journey to Amsterdam to investigate the sections, he declared that he was convinced that this form of ectopic gestation was now possible (Bland Sutton, '01).

In consequence of the difficulties of accurate diagnosis of primary ovarian pregnancy criteria have been laid down by various authors who regard the fulfilment of these conditions as essential to a positive diagnosis of ovarian pregnancy. German writers had accepted the possibility as early as 1850, and in 1878 Spiegelberg laid down his well-known criteria, viz.

(i) That the tube on the affected side must be intact.

(ii) That the foetal sac should occupy the position of the ovary.

(iii) That the sac should be connected to the uterus by the round ligament.

(iv) That ovarian tissue must be found in the wall of the sac.

Williams ('08) modified the last condition by stating that ovarian tissue must be found at several different sites in the wall.

Jacobson ('08) added two further requirements, viz.

(i) That an organic connection between the foetus and ovary must be demonstrated. This condition is sufficiently covered by the demand of Williams.

(ii) That the foetus should be visible in the cavity of the ovum.

The latter condition, which is reminiscent of the statements of Bland Sutton ('00) and Mayo Robson ('02), is unwarranted, as Meyer and Wynne have pointed out (John Hop. Hosp. Bull. No. 338, 1919), because the development of the embryo is retarded by its abnormal environment and is often not recovered after rupture of the gestation sac. In Holland's case ('11), in which the gestation had been of six weeks' duration, the foetus had become converted into an amorphous mass. No embryo was found in 24 out of 43 cases collected by me from the literature. This series included only those cases usually regarded as positive and in which I could satisfy myself, from the descriptions at my disposal, of the presence or absence of the embryo.

Heincke (quoted by Caturani, '14) adds the presence of placental tissue within the ovarian tissue as an additional criterion. But plasmodium may be formed independently of pregnancy, e.g. in cases of chorion-epithelioma of the ovary, sarcoma of the testis, and a dermoid cyst of the anterior mediastrium. Whitehouse ('10), who quotes the above examples, points out, however, that in them plasmodium did not occur alone. This is unlike his case, which he concludes is probably an example of ovarian pregnancy.

Norris ('09) emphasises the importance of examining the corresponding tube microscopically to exclude cases of tubal abortion. He states, "the tube should not only be intact, but should be microscopically free from any evidence of gestation." Chiene ('13) disagrees with this statement and maintains that the removal of the corresponding tube as in his case may not be clinically essential or desirable. Lockyer ('17) nevertheless accepts Chiene's case as

a genuine example of primary ovarian pregnancy. Further Caturani ('14) maintains that a decidual reaction may be present in the corresponding tube in cases of primary ovarian pregnancy.

Of the requirements detailed above, those fulfilled by H 153 are as follows:

(i) The tube on the affected side was intact (macroscopically).

(ii) The tumour is part of the ovarian mass which was connected to the uterus by the ligament of the ovary.

(iii) The ovarian stroma encapsulates the chorionic vesicle or blood clot.

(iv) Chorionic villi are abundantly present.

(v) An embryonic rudiment is visible within the cavity of the ovum.

The condition of Norris that the corresponding tube should be examined microscopically is unfulfilled. However, tubal abortion is not difficult to exclude. The ovarian stroma completely encapsulates the haemorrhagic swelling which contained the chorionic vesicle, and the ovary was quite free from surrounding structures so that at operation the specimen could be removed by the application of an angioclast to the mesovarium.

In this connection it may be pointed out that in van Tussenbroek's classical case the tube was not subjected to microscopic examination. Bryce, Teacher, and Kerr ('08) state in reference to this specimen that "the Fallopian tube was in no way attached to the ovary and, being normal, was obviously not the primary seat of implantation of the ovum." In an editorial of the British Medical Journal (1900, p. 922) the statement is made that van Tussenbroek's specimen proves that ovarian impregnation is a fact no longer to be denied. The existence of a considerable mesovarium and the absence of adhesions are facts stressed in this summary. These desiderata are present in the case of H 153.

DESCRIPTION OF THE SECTIONS

The following description is based upon incomplete celloidin sections 10 μ in thickness and complete celloidin sections 40 μ to 50 μ in thickness. The thick sections proved of considerable value in presenting the topographical relationship of tissues upon which certain conclusions which follow are partly based.

The ovarian capsule.

The capsule is everywhere composed of fibrous tissue. In many parts the nuclei are sparse and the stroma cells can be seen to be arranged in concentric laminae around the blood clot similar to the specimen described by Hewetson and Jordan-Lloyd ('06). In addition there are considerable patches of connective tissue in which the nuclei are abundant. Both types of connective tissue abound throughout the ovary. As already revealed by naked-eye examination the capsule of ovarian tissue was ruptured for the extent of 9 mm. from which blood clot projected. The capsule was fragmentary for some distance beyond the site of rupture. The superficial aspect of this part of the capsule was covered by a thin layer of blood. It is evident that the

rupture of the capsule caused the intraperitoneal haemorrhage found at operation. Such a rupture is probably brought about by a considerable increase of blood surrounding the chorionic vesicle so thinning the capsule until it finally gives way under the internal pressure.

Lea ('10) has pointed out that intraperitoneal haemorrhage in cases of primary ovarian pregnancy may be produced by the penetration of the ovarian capsule by syncytial elements, especially when the implantation cavity is in a superficial position. This occurs relatively infrequently. Examples of its occurrence are provided by the cases described by Boesebeek ('04), Norris and Mitchell ('08), Banks ('12), and Freund and Thomé ('06).

The chorionic villi.

The chorionic villi are to be seen on all aspects of the compressed chorionic vesicle although they are especially abundant at one pole adjacent to the ovary. Here the intervillous spaces are intact. A similar distribution occurred in the cases described by van Tussenbroek ('99), Hewetson and Jordan-Lloyd ('06), and Bryce, Teacher, and Kerr ('08).

Fig. 3. Chorionic villus and wall of the chorionic vesicle showing embryonic blood vessels (× 75).

The villi consist of a loose connective tissue core composed of elongated spindle-shaped cells with well-defined oval nuclei. This connective tissue is continuous with the extra embryonic mesoderm composing the wall of the chorionic vesicle (fig. 3). Blood vessels containing nucleated red blood corpuscles occur in both these situations. The usual double covering of the connective tissue core is present. The cyto-trophoblast consists of a distinct layer of cubical cells—Langhan's layer. The outer layer consists of plasmodi-trophoblast in which nuclei staining darkly with carm-alum are often to be seen arranged in successive rows. Irregular plasmodial processes are also present, some of which abut against the extravasated blood (fig. 4).

The relationship of the villi to the ovarian tissue.

It has already been pointed out that in some cases syncytial elements perforate the capsule of ovarian tissue and so produce intraperitoneal haemorrhage. In Freund and Thome's case ('06) the perforated capsule was

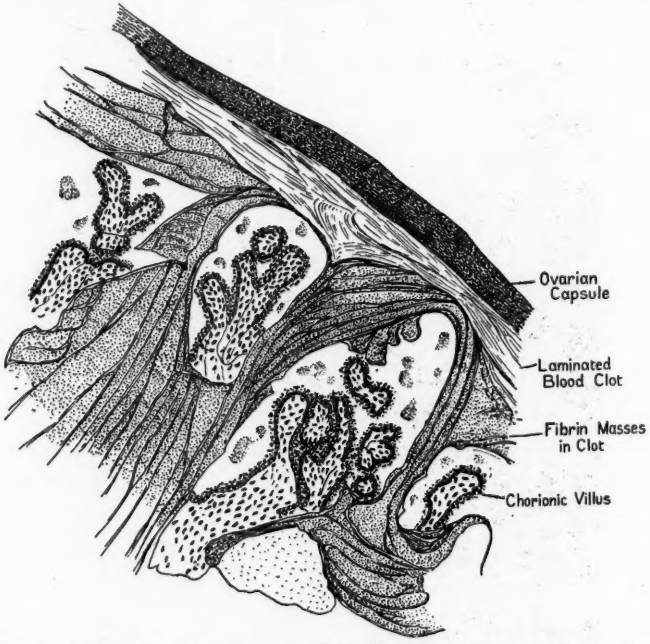


Fig. 4. Showing villi on the external aspect of the chorionic vesicle imbedded in fibrin which separates them from the capsule of ovarian stroma (× 35). (D. J. Farrell, del.)

1–2 cm. in thickness. In the cases of Thompson ('02), Young and Rhea ('11), Hannes ('12), and Caturani ('14), the villi had invaded the surrounding stroma without causing perforation. H 153 is, on the other hand, to be included with the specimens described by Norris ('09), Mall and Cullen ('13), Kelly and

McIlroy ('06), Leon and Holleman ('02), Hewetson and Jordan-Lloyd ('06), Chiene ('13) and Lea ('10), in which the villi do not invade the stroma. A laminated blood clot separates the villi from the capsule of ovarian tissue. Weigart's fibrin stain reveals in H 153 masses of fibrin surrounding the villi, while a firmer laminated clot abuts against the capsule (fig. 4). Holland ('11) ascribes such a condition in the case described by him to recurrent haemorrhages. Recurrent haemorrhages with a very slow circulation of blood in the implantation cavity would account for the appearance in H 153 also. This blood clot in most situations closely surrounds the villi. In one position,

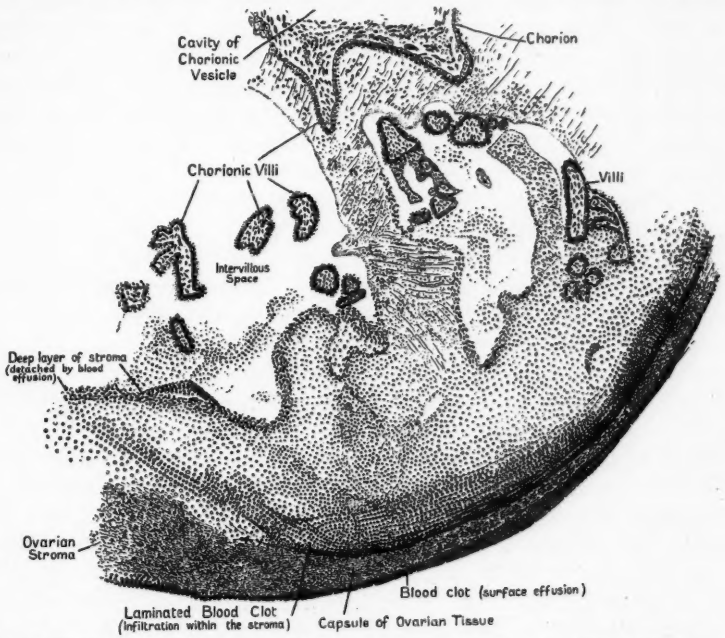


Fig. 5. Showing the intervillous spaces which are preserved at one pole of the chorionic vesicle. Between the surface and the spaces are to be seen three layers, viz. the capsule of ovarian tissue, blood extravasation, and a zone of barrier decidua-like cells (× 20). (D. J. Farrell, del.)

viz. where the villi were found to be most abundant, intervillous spaces are still preserved (fig. 5).

These spaces are bounded by a zone of cells which walls off the laminated blood clot. I believe that this layer originally belonged to the capsule of ovarian tissue. Separation has apparently been effected by an infiltration of blood into the ovarian capsule. Consequently, where the intervillous spaces are present, they will be bounded by a thin necrotic zone of tissue. This zone consists of decidua-like cells. It is separated by a blood-filled interval, 2 to 5 mm. in width from the main mass of ovarian capsule. Therefore, three zones

intervene between the intervillous spaces and the surface of the haemorrhagic swelling, viz. the ovarian capsule, a laminated blood clot, and a barrier zone of decidua-like cells (fig. 5).

An important aspect of this condition is that the deep layer of stroma is very thin. It is on this account that the villi do not establish a firm connection with the stroma, for, in effect, their original connections have been torn away by the blood extravasated into the stroma which encapsulates the implantation cavity. This haemorrhage has distended and eventually ruptured the capsule in H 153, so producing the intraperitoneal haemorrhage which led to operative interference. In the specimen described by Bryce, Teacher, and Kerr ('08) a similar separation of the villi from the capsule has been effected, although in one situation villi came into direct relation with the stroma of the ovary. The authors state that "it is apparent from a study of the sections that considerable haemorrhage has taken place shortly before the operation, and that the blood has more extensively infiltrated the tissue intervening between a layer of necrotic tissue immediately applied to the villi and the more healthy living ovarian tissue forming the outer lamella of the wall of the cavity. A large coagulum was thus formed round the chorionic vesicle and the whole constituted a "fleshy mole" which would doubtless, in short time, have been extruded from the ovary into the peritoneal cavity." This describes accurately the condition found in H 153. Webster ('07) stated that haemorrhage had occurred in the ovarian stroma in his specimen of ovarian pregnancy especially near the placental site. In the Bryce-Teacher uterine ovum a similar haemorrhage was found in the decidua but no extensive infiltration had ensued (cf. Bryce and Teacher ('08), Pl. III).

The marked disturbances of the circulatory mechanism in cases of ovarian pregnancy account, I believe, for the frequency in which the embryo is degenerated or absent. As Kelly and McIlroy ('06) point out the embryo is likely to perish at an early age although the envelopes go on living. Consequently retardation of development of the embryo is not infrequent (cf. Holland ('11), van Tussenbroek ('99), Bryce, Teacher, and Kerr ('08)). Freund and Thomé ('06) believe that the embryo develops normally or not according to the size of the vessels in the region of the implantation cavity and regard the vicinity of the hilum as being the most favourable site. But, on the other hand, a profuse extravasation of blood into the ovarian stroma in the manner shown to have occurred in H 153 would clearly interfere with normal intervillous blood flow and so retard development. Where the intervillous spaces are not preserved degenerating villi are to be found, while the fewness of villi in these situations indicates that some have already been absorbed. In the ovary, as in the tube, lack of decidual reaction has been cited as the cause of the abnormal circulatory condition in the vicinity of the ovum. In a specimen so young as H 153 it is a matter of great interest to determine if there is any definite decidual reaction to be found.

THE REACTION OF THE MATERNAL TISSUES

In H 153 there is a general increase in vascularity of the ovarian stroma which is highly cellular in character. There are hosts of leucocytes in the blood clot against which the villi abut. A similar infiltration of leucocytes has been observed by Mall and Cullen ('13) and Hewetson and Jordan-Lloyd ('06). In general the condition found in H 153 agrees with the statement of Kelly and McIlroy ('06) that the reaction of the ovary in ovarian impregnation resembles that of the uterus in uterine pregnancy. But these authors conclude their discussion of this subject by stating that "nowhere throughout the specimen can tissue be found which has taken upon itself the function or appearance of a decidual layer." They state that lutein cells are present in the fibrin layer which together with some connective tissue cells separate the foetal tissues from the corpus luteum. These decidua-like cells, they believe, are the cells which have been mistaken for true decidual cells by some writers. van Tussenbroek ('99) found large granular necrotic cells which she first interpreted as being due to a decidual reaction. Later she was convinced that these cells were lutein and connective tissue cells. Banks ('12) and Graham ('12) interpret the decidua-like cells present in their specimens as being at least partly trophoblastic in origin.

Only a small minority of observers admit that the decidua-like cells may be the result of a maternal reaction. Bryce, Teacher, and Kerr ('08) acknowledge that many of the large mononuclear cells spread out in the ovarian stroma in their specimen may be maternal in origin. Whitehouse ('10) found similar cells. Caturani ('14) described an attempt at decidual reaction especially around the blood vessels of the stroma. Webster ('04) found a definite decidual reaction lining the intervillous spaces. He denies, however, that ovarian tissue itself is responsible for this change and attributes the reaction to embryonal inclusion of Mullerian tissue in the ovary. In Giles and Lockyer's case ('14) the ovarian stroma contained many large blood vessels and showed decidual reaction in the medulla and cortex. Norris ('09) states that in the specimen described by Franz ('02) there were a few small groups of decidual cells immediately around the ovum. Norris concluded, however, that a study of the literature proved that few authors record "the presence of decidua-like cells and in these the identification is somewhat doubtful." Williams ('08) who also summarised the literature upon this subject was also convinced that a definite decidua was absent in cases of ovarian pregnancy.

The survey of the literature given above, illustrating as it does that the majority of observers speak against a decidual reaction, would tend to convey the impression that the conclusion arrived at by Williams and Norris is a correct one.

After an investigation of H 153 with reference to the occurrence of a true decidual reaction, I am convinced that this condition does occur in the early stages of ovarian pregnancy, so confirming the conclusion of Giles and Lockyer

('14). In discussing the relationship of the chorionic villi to the maternal tissues, the appearances were interpreted by supposing that blood had infiltrated into the ovarian stroma, so separating a thin layer of cells from the main mass and tearing this and the villi away from their connexions with the capsule of connective tissue. This conclusion is based upon the presence of a definite

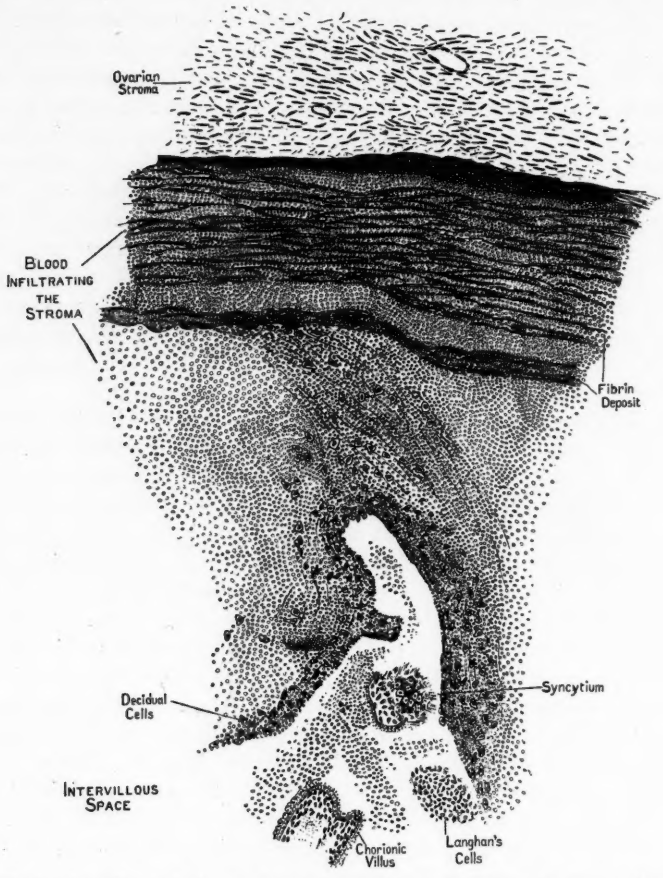


Fig. 6. The barrier cell zone is shown separated from the ovarian stroma by means of an extravasation of blood (× 60). (D. J. Farrell, del.)

layer of cells which is found to bound the maternal aspect of the intervillous spaces (fig. 6). This layer is most perfectly seen where the intervillous spaces are best preserved. If it be followed, it is found to form an imperfect barrier of cells. This is interrupted at various points on account of the haemorrhage in the stroma being in many situations continuous with the blood in the

intervillous spaces. There is no interruption of the barrier layer in one position for the extent of 8 mm. and the layer can be followed on the opposite side of the blood clot which has broken through it (fig. 5). On the external aspect of the chorionic vesicle, it is only represented here and there by groups of cells, which still show the barrier arrangement. But here the intervillous space is imperfect, being continuous to a considerable extent with the blood within the stroma. This is the site at which the villi have already been noticed in a state of degeneration.

The barrier is made up of large elongated, polygonal, oval and pearshaped cells. These are mainly placed concentrically around the intervillous space. The cytoplasm of the cells is stained uniformly with carm-alum and the nuclei are large and conspicuous. With haematoxylin the nuclei are again deeply stained in some of the cells. In others the nucleus is large, oval and more faintly stained.

The decidua-like cells are imbedded in a fibrin layer, scattered cells extending outwards towards the ovarian stroma. In a few sections the ovarian stroma surrounding the implantation cavity has not been infiltrated with blood, and consequently the barrier zone and ovarian stroma are, in these sections, found to be continuous with one another for the extent of 3 mm. Here there is a definite decidual reaction of the stroma and transition stages are to be seen between large darkly staining cells bounding the intervillous space and fusiform connective tissue cells. Similar transition forms were noticed in Hewetson and Jordan-Lloyd's case ('06). This indicates the origin of the large cells from the ovarian stroma. These cells correspond in arrangement, shape and staining reactions with the cells of the barrier layer which lines the intervillous spaces elsewhere. The tissue formed by these cells though not extensive represents an ovarian decidua.

I believe that H 153 illustrates a retrogressive phase with regard to the development of the decidua. The infiltration of blood into the stroma which has separated the barrier zone from the capsule proper has also led to the partial disintegration of this deep zone. Consequently in some situations it is only represented by isolated groups of cells. Extreme difficulty would have been encountered in distinguishing these groups from trophoblastic masses if the continuous lamina of cells forming the ovarian decidua in H 153 had been wholly destroyed.

The difficulty of distinguishing these two types of cells from one another would also have been increased because the stroma of the capsule in H 153, where it has been isolated from the villi in the intervillous space by a considerable blood filled interval, does not present the intermediate stages in the formation of the large decidual cells. These facts probably explain why the decidual reaction in other specimens is less marked than in H 153. It may also explain why isolated decidua-like cells have been found in many specimens which have been interpreted as being wholly foetal in origin. The truth is that the uterus is imitated by the ovary in its reaction not only by leucocytic

infiltration, by increased vascularity and by increased cell formation, but by the formation of true decidual tissue. However, the badly regulated blood flow in the ovary brought about when the plasmodium invades the vessels, leads, in many cases, to bleeding beyond the intervillous space into the ovarian stroma. If this is not arrested, the inner layer of decidua cells becomes stripped away from the stroma and destroyed, and the enlarging cells in the latter resume their normal size, being no longer subject to the direct influence of the trophoblast. As already shown, the uterine decidua surrounding the Bryce-Teacher ovum exhibits a similar infiltration, but this is not extensive, though its effect in this case also was to strip off a zone of maternal tissue. In the ovarian pregnancy of Bryce, Teacher, and Kerr ('08), the infiltration was of a much greater extent than in the uterine decidua, and this fact probably accounted for the relatively few decidua cells found.

Caturani ('14), in speaking of van Tussenbroek's specimen, believes that the lack of decidual reaction accounts for the considerable haemorrhage between the maternal tissue and the oval sac. But I have presented another aspect of the case, viz. that the invasion of comparatively large vessels imbedded in fibrous tissue will probably lead in cases of ovarian pregnancy to relatively profuse haemorrhage independently of the degree of decidual reaction at this stage. I have endeavoured to show that this haemorrhage ploughs up the decidual tissue and separates the villi from their close connexion with the ovarian stroma and consequently the degree of decidual formation is greatly reduced.

A priori, there is no reason why the ovarian stroma cannot react in a manner similar to that of the endometrium. Indeed, decidual reaction has been found on the surface of the ovary in cases of uterine pregnancy as part of the condition called by Taussig ('06) "ectopic decidua formation."

It has been noted above that some observers, e.g. van Tussenbroek ('99), regard decidua-like cells described by them as being lutein in nature. The following description of the corpus luteum and of the relationship of the implantation cavity to it, makes this explanation untenable in the present case.

THE RELATIONSHIP OF THE CHORIONIC VESICLE TO THE CORPUS LUTEUM

A corpus luteum corresponding to the duration of gestation as indicated by the clinical history and confirmed by the degree of development of the chorionic vesicle, is situated within the ovary adjacent to the implantation cavity. It consists of a plicated lamina of large, lightly staining polygonal cells with faintly staining nuclei. On three aspects the lutein lamina is uniform in size. The lamina is infiltrated by connective tissue septa which are already vascularised. Within the lamina of lutein cells there is a delicate connective tissue layer enclosing a central blood clot. A second group of lutein cells form the walls of that part of the corpus luteum which is adjacent to the implantation cavity (fig. 7). These cells also constitute a plicated lamina which is only one-

third of the thickness of the more extensive layer. Externally an uninterrupted layer of connective tissue separates the thinner lutein lamina from the implantation cavity. This layer contains decidua-like cells. Beyond each end of the lamina the internal and external layers of connective tissue become continuous with one another. Lutein cells are absent over considerable areas of these uniting bridges of connective tissue.

There is no direct relationship between the chorionic vesicle and the corpus luteum adjacent to it. The separation of the corpus luteum from the implantation cavity by a layer of connective tissue makes it unlikely that any lutein

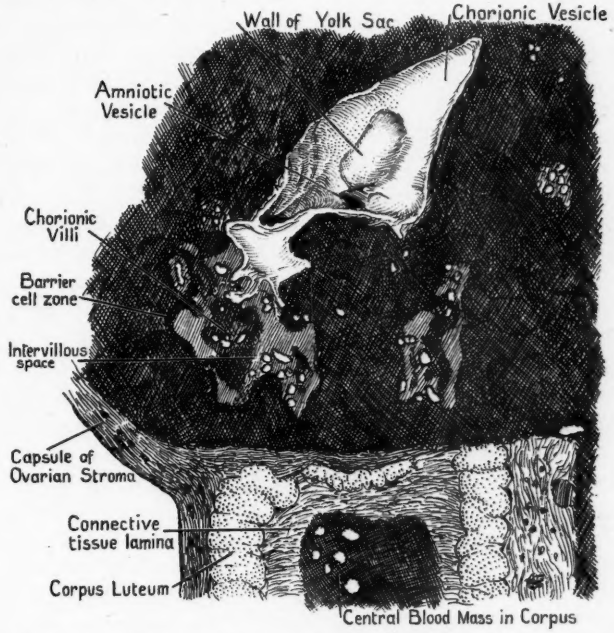


Fig. 7. Drawing from a photograph of a wax plate reconstruction of the chorionic vesicle and embryonic papilla of H 153 showing the relations of surrounding parts. The corpus luteum is shown to be separated from the implantation cavity by a layer of connective tissue (× 5).

cells are spread out in the wall of the gestation sac. Certainly they cannot be present in sufficient numbers to produce the zone of cells found bounding the intervillous spaces described as representing an ovarian decidua.

H 153 is an addition to that class of ovarian pregnancy in which the chorionic vesicle lies wholly outside the corpus luteum. This condition is exhibited in the specimens described by Hewetson and Jordan-Lloyd ('06), Thompson ('02), Webster ('04), Franz ('10), and Bryce, Teacher, and Kerr ('08). Whitehouse ('10) also described a specimen in which plasmodial masses were situated wholly outside a cystic corpus luteum.

The problem is to account for the extra-follicular position of the ovum in these cases.

A summary of the views of various authors in regard to the imbedding of the ovum is given by Graham ('12). This writer is himself of the opinion that imbedding occurs in an epithelial lined tubule cut off from the fimbriated extremity of the Fallopian tube and that the ovum is attracted towards the corpus luteum. Webster ('04) believes that the fertilised ovum is imbedded in Mullerian duct inclusions which react to form a decidua, and that imbedding is extra-follicular. The wide distribution of ectopic decidua in cases of uterine pregnancy proves that such inclusions are unnecessary to provide a decidual reaction. Moreover, the large epithelial cells described by Graham and Webster are not consistently found in cases of ovarian pregnancy. In H 153 there is no justification for the view that the decidua cell barrier has arisen from Mullerian tissue. On the contrary, its connective tissue origin is displayed in those sections where the ovarian stroma directly bounds the intervillous spaces. In Hewetson and Lloyd's specimen a layer of connective tissue completely separates the implantation cavity from the corpus luteum as in H 153. The authors believe that the ovum was fertilised after extrusion from the Graafian follicle, and that the fertilised ovum then invaded the ovary at a higher level. They suggest that the grafting on the ovary may be due to the retention of the fertilised ovum in a crypt or by adhesions. Such cases are distinguished by Spiegelberg as epiovarian. Although the possibility of such an occurrence cannot be excluded it is unlikely. However, the presence of inflammation of the ovary has been mentioned by Caturani as a possible aetiological factor in the production of ovarian pregnancy. Inflammatory processes of the ovary and in some instances of the tube in cases of ovarian pregnancy have been described by Caturani ('14), Norris ('09), Lockyer ('17), Young and Rhea ('11) and Bandel ('02). No adhesions were to be found in the case of H 153. Yet, in order to invade the ovary from without, it must be supposed that in some way the fertilised ovum was retained in the vicinity of the ovary until its trophoblastic layer was developed. Bryce, Teacher, and Kerr ('08) while admitting the possibility of such an invasion in Hewetson and Jordan-Lloyd's specimen suggest an alternative explanation for the occurrence of such cases in which connective tissue surrounds the implantation cavity. They believe that the ovum was primarily imbedded in the thin layer of connective tissue within the corpus luteum and that it burrowed through the wall of the corpus to reach its extra-follicular position. Although the chorionic vesicle was extra-follicular in the specimen described by Bryce, Teacher, and Kerr ('08), a gap was present in that part of the wall of the corpus luteum which adjoined the implantation cavity. A similar gap occurred in the specimen described by Franz ('02). Bryce, Teacher, and Kerr state, in describing their specimen, that at the site of interruption of the corpus luteum, "the gestation sac is directly continuous with the interior of the corpus luteum by a band of tissue of doubtful character and more or less in a state of necrosis."

They interpret this strand as being comparable to the cone of fibrinous material occupying the point of entrance of the Bryce-Teacher ovum. Their conclusion is, therefore, that the ovum had been fertilised within the follicle and while only about ·2 mm. in diameter migrated through the wall of the corpus luteum to become imbedded in the surrounding vascular connective tissue.

However, Bryce, Teacher, and Kerr admit a second possibility, viz. "that the ovum was arrested between the lips of the wound of the follicle, was there fertilised, and was then imbedded in the vascular stroma outside the follicle." As they point out, this may explain Thompson's case ('02) which lay "in the splayed out mouth of the follicle with no lutein tissue either on its free surface or between it and the corpus luteum." However, since in their younger specimen the chorionic vesicle was wholly outside a corpus luteum they favour the first alternative. They state that if the vesicle had continued to grow the corpus luteum would have been invaded and destroyed as in Thompson's case. They regard the migration theory as a more complete analogy to the conditions found in uterine implantation. They believe that all cases may be explained by assuming that they were primarily intra-follicular and only vary from one another in the degree of penetration of the connective tissue. They agree with van Tussenbroek that in her case the ovum imbedded itself excentrically in the connective tissue within the lutein lamina. If such an ovum progressed, the final result would again be destruction of the corpus luteum. This explanation adheres to van Tussenbroek's original definition that "ovarian pregnancy means pregnancy in an ovarian follicle."

A study of H 153 which is at least in the same age period as the specimen described by Bryce, Teacher, and Kerr has convinced me that it is possible for the fertilised ovum to become primarily implanted in the connective tissue surrounding the mouth of the ruptured follicle. This is the alternative explanation which is dismissed by Bryce, Teacher, and Kerr. There is no cone of necrosed tissue joining the gestation sac with the interior of the corpus luteum in H 153 as in their specimen. Moreover, although the size of the lutein layer adjacent to the implantation cavity is reduced, it is nevertheless a well-formed plicated lamina. The reduction in size is readily explainable by the probability that the vascularisation of the area in which it is growing is interfered with due to the proximity of the implantation cavity.

The appearance in H 153 suggests that the ovum, together probably with cells of the discus proligerus still attached to it, was entrapped in the blood clot closing the wound of the ruptured follicle. Spermatozoa probably fertilised the ovum while lying in this situation as the coagulum formed. After the development of the trophoblast the ovum seems to have imbedded itself in the connective tissue surrounding the original opening and here development proceeded. In this case the growing ovum has formed for itself a capsule consisting of a thin outer layer of stroma, and a deep layer of connective tissue, separating the implantation cavity from the corpus luteum.

With the data presented by H 153 the early ovarian pregnancy of Bryce,

Teacher, and Kerr no longer occupies a unique position. In H 153 the cone of necrosed tissue described by Bryce, Teacher, and Kerr is not present. If their explanation that it is formed by the outward migration of the ovum were correct, it should be still visible in this specimen of corresponding age if this migration had taken place. Moreover, another explanation may be given to the necrosis of the lutein wall described by these authors, viz. that invasion of the corpus luteum by a growing ovum primarily implanted outside the follicle is in progress. They themselves state that "only at one point does the chorion come close to the ovarian stroma and that is opposite a gap in the wall of the corpus luteum."

The further progress of development of a growing chorionic vesicle primarily imbedded outside the follicle would be identical with that described by Bryce, Teacher and Kerr for specimens which have secondarily invaded that tissue, viz. the corpus luteum will be invaded and finally will disappear. It is thus not unlikely, as suggested by Webster in 1904, that many cases obtained at a comparatively late stage of development described as follicular because of the presence of lutein cells in the gestation sac, may have been imbedded in the first instance in the thecal connective tissue and not in the follicle at all. In this connexion it is interesting to note that the extra-follicular specimens so far described are early specimens which suggest that extra-follicular imbedding is not uncommon. Probably, as suggested by Thomson ('19), ovarian pregnancy may be produced by fertilisation of an ovum which has not been expelled from the follicle, and some cases are to be explained in this way. But it is certain that van Tussenbroek's original definition which includes only such cases must be replaced by a more comprehensive statement to include primary imbedding outside the follicle as well.

SUMMARY AND CONCLUSIONS

The specimen described in this paper (H 153, Anat. Dept. Collection, Sydney University) has been shown from clinical and histological data to be an example of primary ovarian pregnancy of less than 20 days' duration. The embryonic papilla (3·5 mm. in length) was enlarged by the infiltration of maternal blood into the yolk sac through the body stalk. The compressed chorionic vesicle measured 10 × 4·7 mm. The specimen is of special value due to the early period of development. The following conclusions were derived from a consideration of its features.

(1) That a decidual reaction probably always occurs in early stages of ovarian impregnation.

(2) That the decidual tissue in H 153 is ploughed up by infiltration of the ovarian stroma by blood from the intervillous space; this infiltration has detached the villi from their attachments and probably led to retardation of growth of the chorionic vesicle and embryonic rudiment.

(3) That the ovum was fertilised as the closing coagulum was formed in the mouth of the Graafian follicle and proceeded to develop in the con-

nective tissue in this situation, imbedding itself *ab initio* outside the growing corpus luteum of pregnancy. It appears that ovarian pregnancy may result from the fertilisation and imbedding of an ovum within its follicle or at any point of its course in its progress outwards.

In conclusion I wish to express thanks to Messrs Schaeffer, Burfield and Bagnall of the University of Sydney for the technical assistance rendered me in the preparation of this account.

REFERENCES

('01) Anning, G. P. and Littlewood, H. "A Case of Primary Ovarian Pregnancy." *Trans. Obstets. Soc.* xliii, p. 14. London, 1901.

('10) Barrows, C. C. "Ruptured Ovarian Pregnancy." *Amer. Journ. Obstet.* lxii, pp. 1078–1081. New York, 1910.

('12) Banks, A. G. "A Case of Ovarian Pregnancy." *Journ. Obstet. Gyn. Brit. Emp.* xxi, pp. 216–219. 1912.

('02) Bandel, R. *Beitr. z. Klin. Chir.* xxxvi, p. 657. 1902.

('96) Bland Sutton. *Surgical Diseases of the Ovaries and Fallopian Tubes*, p. 35. 1896.

('01) —— *Brit. Med. Journ. Vide* Discussion of Anning and Littlewood's specimen. 1901.

('04) Boesebeek. *Monat. f. Geb. u. Gyn.* Berlin, 1904. *Vide* Norris ('09).

('10) Bondi, Josef. *Wiener Klinische Wochenschrift*, p. 774. 1910.

('08) Bryce, Teacher and Monro Kerr. *Dev. and Imbedding of Human Ovum. An Early Ovarian Pregnancy.* Glasgow, 1908.

('14) Caturani, M. "Ovarian Pregnancy with Report of a Case." *Amer. Journ. of Obstets.* lxix, pp. 409–428. 1914.

('13) Chiene, G. "Ruptured very early Ovarian Pregnancy." *Obstet. Trans. Edin.* xxxviii, p. 96. 1913. Also *Edin. Med. Journ.* x, p. 316.

('00) Croft. "On an Anomalous Case of Extra-uterine Pregnancy probably Ovarian." *Trans. London Obstet. Soc.* xlii, p. 316.

('02) Franz, K. "Ueber Einbettung und Wachstum des Eies im Eierstock." *Hager's Beiträge z. Geb. u. Gyn.* vi. 1902. *Vide* Bryce, Teacher and Kerr ('08).

('06) Freund, H. W. and Thomé, R. *Virchow's Archiv f. Path. Anat.* Bd clxxxiii, Heft i. 1906. *Vide* Kelly and McIlroy ('06).

('14) Giles, A. E. and Lockyer, C. "A Case of Ovarian Pregnancy." *Proc. Roy. Soc. Med.* viii, pp. 2–10. 1914–15.

('12) Graham, G. S. "A Case of Ovarian Pregnancy." *Journ. Med. Res.* xxvi, pp. 499–512. 1912.

('13) Grimsdale, T. B. "Case of Ovarian Pregnancy with Full Time Foetus." *Journ. Obstet. and Gyn. of Brit. Emp.* xxiii, pp. 115–117. 1913.

('12) Hannes, W. "Ovarian-Gravidität." *Zeitschrift für Geburtsch. und Gynäkologie*, lxxii, pp. 269–271. 1912.

('09) Hastings, Tweedy. "A Specimen of Ovarian Pregnancy." *Proc. Roy. Soc. Med.* iii, pt. 2. 1909–10.

('06) Hewetson and Jordan-Lloyd. *Brit. Med. Journ.* ii, p. 568. 1906.

('11) Holland, Eardley. "A Case of Ovarian Pregnancy probably Bilateral." *Journ. Obstet. and Gyn. of Brit. Emp.* xx, pp. 295–298. 1911.

('21) Hunter, J. I. "A Case of Early Primary Ovarian Pregnancy." *Med. Journ. Australia*, ii, No. 13, p. 233. 1921.

('08) Jacobson, S. D. *True Primary Ovarian Pregnancy. Contributions to the Science of Medicine and Surgery, New York Post Grad. Med. School and Hosp.* p. 241. 1908.

('06) Kelly, J. K. and McIlroy. *Journ. Obstet. and Gyn. of Brit. Emp.* ix, p. 389. 1906.

('08) Kerr, J. M. M. "Case of Ovarian Pregnancy associated with an Intra-uterine Pregnancy." *Proc. Roy. Soc. Med.* i, No. 9, p. 268. 1908.

('10) Lea, A. W. W. "A case of Ovarian Pregnancy with Diffuse Intraperitoneal Haemorrhage." *Journ Obstet. and Gyn. of Brit. Emp.* xv, pp. 182–187. 1910.

('12) LENDON, A. A. *Aust. Med. Gaz.* XXXI, p. 492. 1912.
('02) LEON, M. DE and HOLLEMAN. *Rev. de Gyn.* June, 1902. *Vide* KELLY and MCILROY ('06).
('17) LOCKYER, C. "Two Cases of Primary Ovarian Pregnancy." *Proc Roy. Soc. Med.* X, No. 8, p. 169. June, 1917.
('15) MALL, F. P. "Tubal Pregnancy." *Surg. Gyn. Obstet.* XXI, pp. 289–298. 1915.
*('13) MALL, F. P. and CULLEN, E. K. "An Ovarian Pregnancy located in the Graafian Follicle." *Surg. Gyn. Obstet.* XVII, pp. 698–703. 1913.
('02) MAYO ROBSON. "Primary Ovarian Gestation." *Trans. Lond. Obstet. Soc.* XLIV, p. 215. 1902. Also *Brit. Med. Journ.* II, p. 1447. 1902.
('08) NORRIS, C. C. and MITCHELL, C. B. "Primary Ovarian Pregnancy with Report of a Case." *Surg. Gyn. Obstet.* p. 460. May, 1908.
('09) NORRIS, C. C. "Primary Ovarian Pregnancy. The Report of a Case combined with Intrauterine Pregnancy." *Surg. Gyn. Obstet.* IX, p. 123. 1909.
('13) OLDFIELD, C. "Ovarian Gestation." *Journ. Obstet. Gyn. Brit. Emp.* XXIII, pp. 41, 42. 1913.
('21) RAY, H. M. "Primary Ovarian and Primary Abdominal Pregnancy: Their Morphological Possibility." *Surg. Gyn. Obstet.* XXXII, No. 5, p. 437. 1921.
('78) SPIEGELBERG, OTTO. *Arch. f. Gyn.* VIII, p. 73. 1878. Also "Text-book of Midwifery," *New Sydenham Soc. Trans.* p. 429.
('06) TAUSSIG. "Ectopic Decidua Formation." *Surg. Gyn Obstet.* p. 292. March, 1906.
('98) TAYLOR, J. W. "Ingleby Lectures." *Lancet*, p. 1447. May, 1898.
('02) THOMPSON, J. F. *Trans. Amer. Gyn. Soc.* XXVII, p. 338. 1902. Quoted by KELLY and MCILROY ('06).
('19) THOMSON, ARTHUR. "Rupture of the Graafian Follicle." *Journ. of Anat.* LIV, Pt 1. 1919.
('99) VAN TUSSENBROEK, CATHERINE. *Annales de Gyn. et Obstet.* Dec. 1899. Quoted by BRYCE, TEACHER, and KERR ('08).
('12) VERCO, W. A. "Ovarian Pregnancy." *Aust. Med. Gaz.* XXXI, p. 491. 1912.
('02) WEBSTER, J. C. *Amer. Journ. Obstet.* XLV, p. 302. 1902.
('04) —— "Study of Ovarian Pregnancy." *Amer. Journ. Obstet.* L, pp. 28–50. 1904.
('07) —— *Trans. Amer. Gyn. Soc.* XXXII, p. 122. 1907.
('10) WHITEHOUSE, B. "Remarks on a case of Probable Ovarian Pregnancy." *Brit. Med. Journ.* I, pp. 1276–1280. London, 1910.
('08) WILLIAMS, WHITRIDGE. *Kelly and Noble's Gynaecology*, 1908.
('17) —— *Text-book of Obstetrics*, 1917.
('11) YOUNG, E. B. and RHEA, L. J. "Ovarian Pregnancy: Report of a Case." *Boston Medical and Surgical Journ.* CLXIV, p. 264. 1911.

[* *Note.* Since this article has been in the press *Contributions to Embryology*, Vol. XII, No. 56, Washington, 1921, which includes "Ovarian Pregnancy" by F. P. Mall and A. W. Meyer, has become available.]

THE ORIGIN OF THE MOTOR NEUROBLASTS OF THE ANTERIOR CORNU OF THE NEURAL TUBE

By RAYMOND A. DART, M.Sc., M.B., Ch.M.

AND

JOSEPH L. SHELLSHEAR, M.B., Ch.M.

Demonstrators of Anatomy, University College.

INTRODUCTION

The foundation of His' conception lies in the ectodermal or neural tube origin of motor neuroblasts. It is essential therefore to analyse carefully the evidence of those who have actually dealt with this phase of the question. With few exceptions the His conception has been given a false appearance of certainty by writers having assumed this neural tube origin from the results of His, Ramón y Cajal, and Schaper.

As recently as 1921 Neal writes "That neuraxones develop as processes of ganglion cells scarcely admits of reasonable doubt in the light of the evidence now in our possession. Few to-day would challenge the truth of Harrison's assertion that the work on the cultivation of tissues may be said without reserve to have completely proved the correctness of the conception of His and Ramón y Cajal."

Coordinated movements occur in the embryo at a time antedating the first appearance of ganglion cells and at a stage in development before those stages on which His, Ramón y Cajal, and Schaper worked. Such being the case the problem must be reinvestigated, for the origin of any structure or mechanism must go back to the ultimate beginnings, and these certainly antedate the stages which these men describe.

His depicts no stages earlier than Pristiurus of 4·5 mm. in length and Cajal makes his deductions from chicks at stages from 72 hours onwards.

The work of Harrison on the cultivation of tissues is undoubtedly a demonstration of the protoplasmic activity of nerve cells in general, but upon the subject of the site of origin of the cells we are particularly dealing with, it gives us no information whatever. Further, as Harrison stated in one of his papers, "There is nothing in the present work which throws any light upon the process by which the first connection between the nerve fibres and its end organ is established." We must therefore emphasise at this point that, no matter how instructive researches and experiments may be on the development of axonic processes, if the somites are so functioning as to give rise to movements in the embryo before nerve-fibres, or even ganglionic cells, are demonstrable in the embryo, such researches as these can give us no certain

information as to the *origin* of the mechanism concerned in the production of these movements.

Some consider neuro-fibrillae to be the first evidence of "effector" activity, but the demonstration of these in an embryo after the advent of coordinated movements merely points to a later differentiation going on in a mechanism already established.

Our aim is to demonstrate the origin of these motor neuroblasts from the myotomes and to establish the principle of both functional and structural continuity between the nervous system and the other systems which it controls.

TERMINOLOGY

The motor neuroblast is frequently referred to as the effector neuroblast or neurone when referring to the elements in the reflex arc.

On the sensory side, as Huxley so clearly pointed out, we have (1) the *receptor*, a modified epithelial organ, (2) the nerve and ganglion or cell *transmittor*, and (3) the *sensorium*; whereas on the effector side we have only the term *effector* used, in some cases distinctly referring to the neurone itself, in others to the structure effected, or the two elements as a whole unit. In this paper the term "*effector*" is used for the motor neuroblast (or neurone) and we propose to introduce the term "*expressor*" for the organ acted upon by the effector neurone, be it muscle, electric organ, or other structure; and thus the term "*expressor*" on the motor side is similar in use to the term "*receptor*" on the sensory side.

Thus we could describe a simple reflex arc in the following terms: *receptor*, *transmittor*, *sensorium*, *effector*, *expressor*. The old term *neuro-muscular*, revived by Parker and others, in the case of undifferentiated primitive tissue is open to great objection because such tissue is neither neural nor muscular in that it is undifferentiated. Although the meaning of the term may be clear, in many cases its ambiguity becomes obvious when the undifferentiated tissue of the myotomes, or of the embryonic heart, is directly compared with adult fully differentiated muscle. The substitution here of the term *effector-expressor* seems to us less open to objection. Furthermore it clarifies the general conception of the so-called "independent-effectors" by dividing them into two obvious classes: *independent expressors* and *independent effector-expressors*.

EVIDENCE OF COORDINATED ACTIVITY

Recent work on unicellular organisms shows that the cilia, the *expressors* are coordinated by impulses from *receptors* in the cirri and we thus find the earliest expression of complicated coordination even in the unicellular organism. Parker shows in Invertebrata a definite *effector-expressor* (neuro-muscular) undifferentiated tissue. Obviously we have need of a conception sufficiently broad to comprehend these activities as well as those of higher forms. By such a conception the components of the *effector-expressor* mechanism are traced

back to their sources, or, better still, common source in the single *indifferent* cell.

We ourselves have observed movements of a coordinated character with abduction and adduction in embryos before the appearance of sensory neuroblasts, and when the apparent relationship between the neural tube and the myotome is one of contact. Such evidence has been to hand since Balfour, who, in his famous monograph on Elasmobranch fishes, states,

"Before the appearance of the third visceral cleft in a part of the innermost layer of each protovertebra (which may be called the splanchnic layer from its being continuous with the mesoblast of the splanchnoplane) opposite the bottom of the neural tube, some of the cells commence to become distinguishable from the rest and to form a separate mass. This mass becomes much more distinct a little later, its cells being characterised by being spindle shaped and having an elongated nucleus which becomes deeply stained by reagents. Coincidently with its appearance the young dog-fish commences spontaneously to move rapidly from side to side with a kind of serpentine motion, so that, even if I had not traced the development of this differentiated mass of cells till it becomes a band of muscles close to the notochord, I should have had little doubt of its muscular nature. It is indicated by the letters *mp* (in figs. 11, 12, and 13). Its early appearance is most probably to be looked upon as an adaptation consequent upon the respiratory requirements of the young dog-fish necessitating movements within the egg.

Shortly after this date, at a period when three visceral clefts are present, I have detected the first traces of the spinal nerves." Cf. fig. 1 of this paper.

Wintrebert (1904), and Paton (1906), have confirmed this demonstration of Balfour's. Furthermore, Paton points out that the primitive movements of abduction and adduction of the body begin at a time when these phenomena "may as yet neither be designated as myogenic or neurogenic in origin." So, Paton describes for the vertebrate embryo phenomena comparable with those designated by Parker as *neuro-muscular* in lower invertebrates.

If the His conception is correct, there is, at this stage, no connection whatever between the neural tube and the myotomes. The *effectors* are in the neural tube and have not yet grown out to the *expressor* organ. How then are there coordinated movements of abduction and adduction?

Of those who stand for discontinuity between the neural tube and myotome, Balfour alone would appear to have appreciated the significance of this question. Keen student of phylogeny as he was, he saw the origin of the *effector-expressor* mechanism from a common source (as also did Gaskell) and he failed to account for the apparently insurmountable difficulty in any other way than by a pathologic-like lesion.

Before describing in detail the actual histological appearance of various embryos at this age, it is expedient to quote Balfour in full on this point:

"General considerations. One point of general anatomy upon which my observations throw considerable light is the primitive origin of the nerves. So long as it was admitted that the spinal and cerebral nerves developed in the embryo independently of the central nervous system, their mode of origin

always presented to my mind considerable difficulties. It never appeared clear how it was possible for a state of things to have arisen in which the central nervous system as well as the peripheral termination of nerves, whether motor or sensory are formed independently of each other; while between them a third structure was developed, which, growing out either towards the centre or towards the periphery, ultimately brought the two into connection. That such a condition could be a primitive one seemed scarcely possible.

...It is possible to suppose that in their primitive differentiation contractile and sensory systems may, as in Hydra, have been developed from the protoplasm of even the same cell.

...When such a condition as that was reached the sensory portion of the cell would be called a ganglion cell, or, terminal sensory organ, the connecting process a nerve, and the contractile portion of the cell a muscle cell. When these organs were in this condition, it might not impossibly happen for the general developmental growth, which tended to separate the ganglion cell and the muscle cell, to be so rapid as to render it impossible for the growth of the connecting nerve to keep pace with it and that thus the process connecting the ganglion cell and the muscle cell might become ruptured. Nevertheless the tendency of the process to grow from the ganglion cell to the muscle cell, would remain, and when the rapid developmental growth had ceased, the two would become united again by the growth of the process which had previously been ruptured."

From our present knowledge of the origin of sensory neuroblasts, of the constitution of the neurones, and of primitive neuro-epithelial and neuro-muscular cells, it is evident that to establish His' conception, the demonstration of some pathologic-like lesion is logically necessary, but even then the presence of coordinated movements of abduction and adduction would be entirely unexplained.

THE HISTOLOGICAL APPEARANCE OF THE EMBRYO AT THE TIME OF THE FIRST APPEARANCE OF COORDINATED MOVEMENTS

Fig. 1 is a section of a drawing of *Squalus acanthias* (No. 1498, Sect. 110, 8μ) from the embryological collection at Harvard inaugurated by Dr C. Sedgwick Minot.

This embryo is described as being 3·8 mm. in length and shows the actual appearance of the embryo when the first movements occur. It corresponds almost exactly with Balfour's figures. The myotome shows the differentiation and thickening of the inner wall (fig 1 *b*). In the interval between the myotome and notochord is to be seen the commencement of the so-called *breaking-down* of the inner wall of the myotome. The relationship between the myotome and neural tube is certainly one of *contact*, but it is not possible in this specimen to determine continuity.

Fig. 2, *Squalus acanthias*, 4·0 mm. (H. C.) (No. 7050 *a*, Sect. 106, 10μ) shows a further stage in the differentiation of the myotome.

Protoplasmic continuity between the myotome and neural tube is now very definitely established.

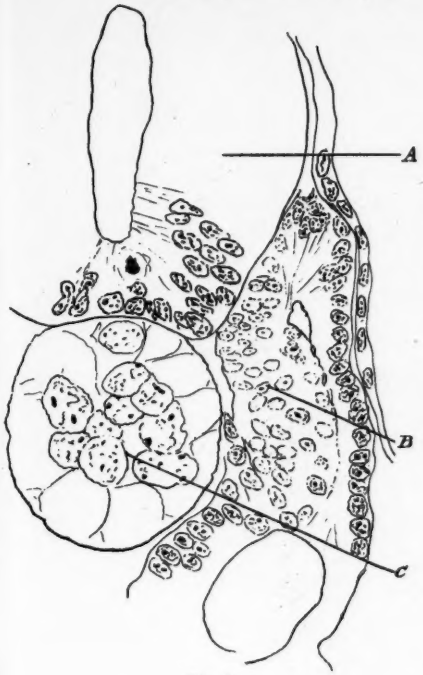


Fig. 1.

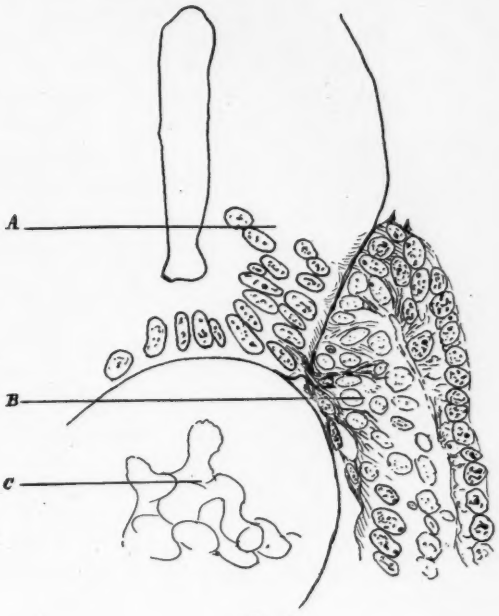


Fig. 2.

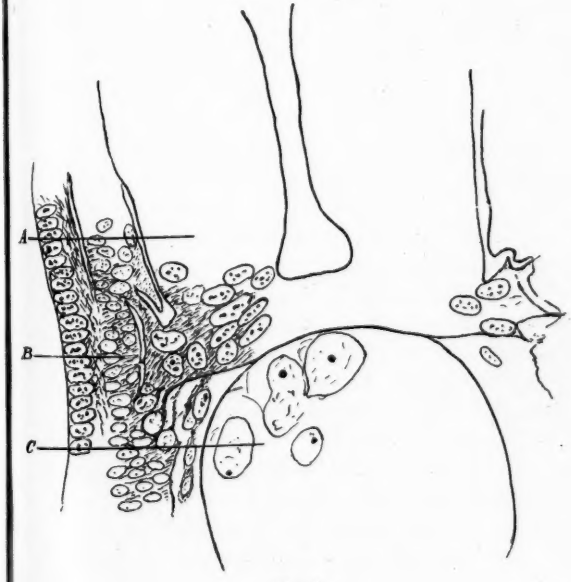


Fig. 3.

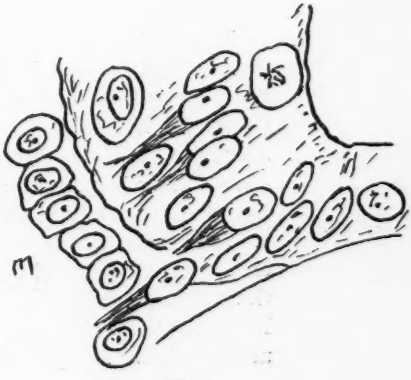


Fig. 4.

The differentiation of the inner wall reveals the type of tissue shown in fig. 1, for we see the beginnings of the division of the *effector-expressor* mechanism of the myotome into its two components *effector* and *expressor*. As to which of the cells lying outside the neural tube are motor neuroblasts, there is nothing in the specimen to tell. The cells are *indifferent*.

Fig. 3. *Squalus acanthias*, 5·2 mm. (H. C.) (No. 1355 *a*, Sect. 251) shows a later differentiation. For further evidence as to the nature of these cells readers are referred to Held's monograph in which similar stages are clearly depicted.

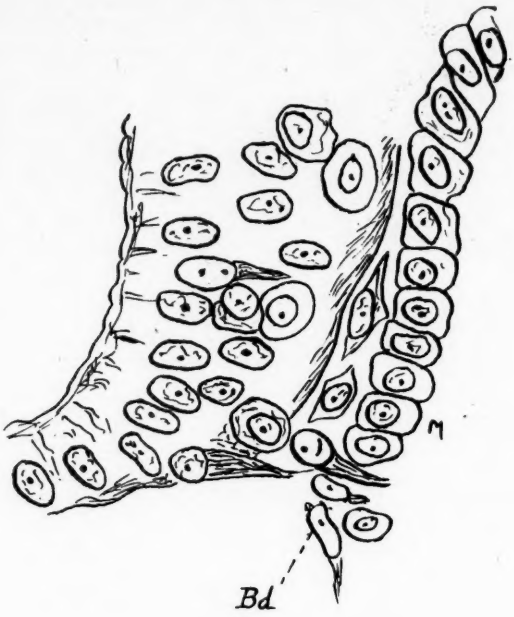


Fig. 5.

His publishes in his paper on the development of neuroblasts numerous pictures of *Pristiurus* in the same stages. He regarded the myotome of so little account that in all but a few pictures he leaves it out altogether. Comparing his pictures, however, of embryos of 4½ mm. with fig. 2, we note a striking similarity between his figs. 38 and 39. He depicts a *breaking-down* of the myotome in the same area as fig. 2. We do not desire to fall into the error of assigning to the so-called sclerotome a purely neuroblastic function. We are alive to the outcome of this having been done in the case of the "neural crest." Placodes give rise to neuroblasts and connective tissue. We consider that the inner wall of the myotome belongs to this *placodal* type of structure. But whereas we do not at this stage commit ourselves as to which cells are neuroblasts in the figures of this paper, His did commit himself and depicts

neuroblasts outside the neural tube at this early period. The study of his figures leaves the impression that these cells have come from the myotome. His' figs. 38 and 39 are reproduced as figs. 4 and 5. His proof that these motor neuroblasts are derived from the germinal layer of the neural tube will be found on pages 323 and 324 of his paper, "Die Neuroblasten und deren Entstehung im Embryonalen Mark."

Briefly stated, his proof rests on two facts:

(1) That the site of origin of the motor neuroblasts is the germinal layer, for when he sees the motor neuroblasts (in the outer part of the neural tube) present, there are holes in the ependymal layer from which they have sprung.

(2) That the cubic capacity of a protoplasm of a germinal cell allows of sufficient volume of material to stretch from the neural tube to the myotome:

"das Volum der Gesammtzelle ... ... 697 cub.μ
„ des Kernes ... ... 65 „
„ des Zellenleibes ohne den Kern 632 „

Die Breite eines Axencylinders beträgt (mit einem Nadelzirkel am Projectionsbilde des Zeichnungsprismas gemessen) ca. 0·9μ. Aus obigen 632 cub.μ Protoplasma würde demnach eine Faser von rund 250μ Länge gebildet werden können."

Our criticism is not simply captious, for it is remarkable that His was able to determine so much with material showing such obvious lacunae after preparation. But surely the time has come for a reconsideration of this problem, and with evidence other than that used seriously by His.

Figs. 6 and 7 are, respectively, *Squalus acanthias*, 6 mm. (No. 293, Sect. 208, 10μ) and 7·5 mm. (No. 149, Sect. 404, 8μ), both (H. C.). They show the further changes in the myotome and region between the myotome and neural tube. These figures illustrate the banking up of the nuclei lying in the protoplasm between the neural tube and the myotome. The inner wall of the myotome is reduced in thickness and in the number of rows of nuclei, whether due to growth of the embryo or to change in position of nuclei it is difficult to express an opinion. For comparison with figs. 3, 6 and 7, we represent figs 8, 9 and 10, which are a continuation of His' pictures. If histological evidence is our criterion, these pictures clearly point to a centripetal rather than a centrifugal movement, for the neuroblasts are outside the neural tube in the early stages and inside in the later stages although no explanation of the relative change in position of the motor neuroblasts is offered by His.

DISCUSSION OF EVIDENCE

On the evidence so far as we have represented it, certain facts stand out:

(1) A mechanism capable of coordinated movements is in existence in very early stages in the embryos of those vertebrates which take on a free existence at an early stage in ontogeny.

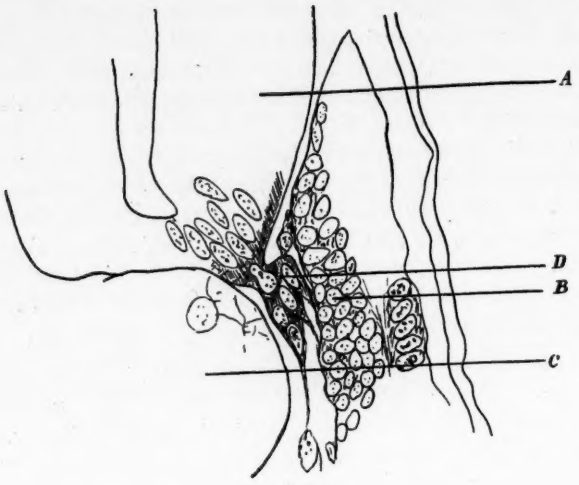


Fig. 6.

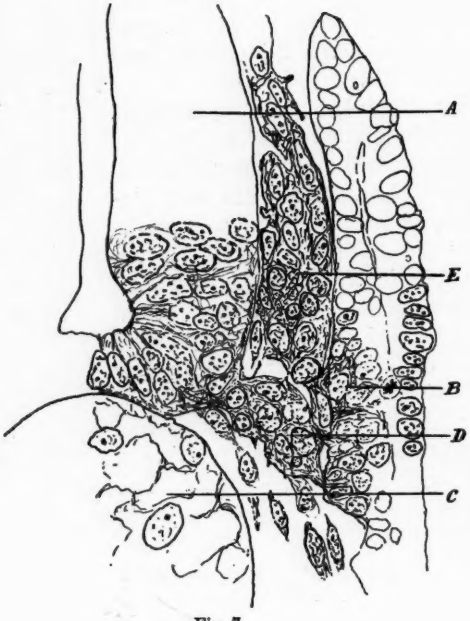


Fig. 7.

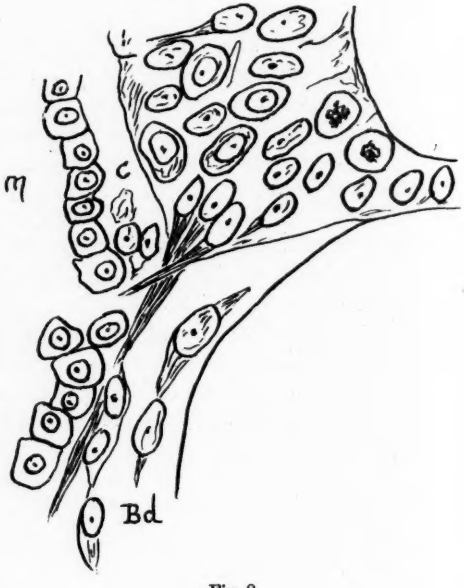


Fig. 8.

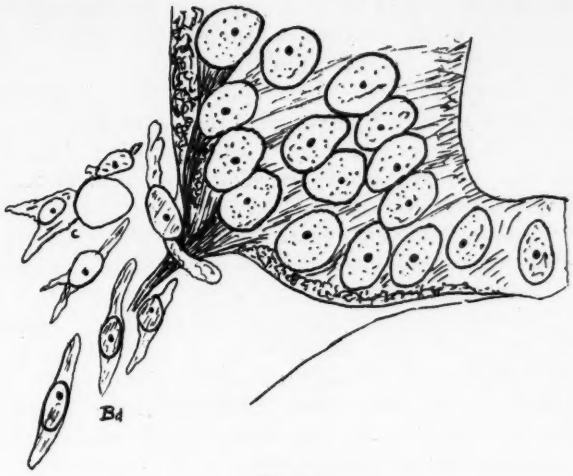


Fig. 9.

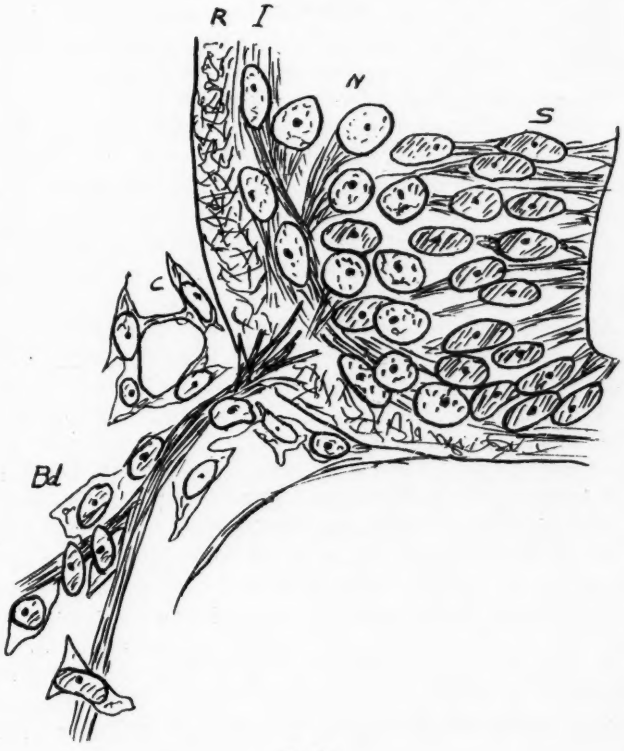


Fig. 10.

(2) This mechanism is in the myotome itself, and the subsequent differentiation of the myotome reveals the stage of development chosen by most investigators for the solution of the problem.

(3) If there is no protoplasmic continuity between the myotome and the neural tube at these earliest stages, and if the motor neuroblasts are in the neural tube, His' hypothesis can give us no explanation of the behaviour of the embryo unless we suppose that the adult mechanism has no relationship with the primitive embryonic mechanism.

(4) In *Squalus acanthias* the motor ganglion outside the neural tube is seen in fig. 7 to be in the same stage of development as the so-called neural crest (in the sense of recent text-books).

Thus the nuclei belonging to the motor neurones would seem to be differentiated from the myotome at a time which synchronises with the formation of sensory neuroblasts from neuroepithelium. This is no chance circumstance, but it reveals to us a definite phylogenetic story. We have developed an *effector-expressor* mechanism to respond to a *receptor-transmittor* mechanism. In brief, we have a vivid demonstration of the fact that the myotomic mechanism was developed in response to the exteroceptive side of the reflex arc.

By the development of the segmentally repeated reflex arc, characterised by its "invariability of response," the animal kingdom becomes to a greater extent the master of its environment; the development of such a mechanism is the common characteristic of all animals with a segmented mesoderm, i.e. of the Annulata and higher Invertebrata and of the Vertebrata. The neural tube (or *sensorium*) itself is the later and typically vertebrate achievement in phylogeny developed for more accurate coordination and association.

So far the problem has been approached from the standpoint of the lack of protoplasmic connection between the neural tube and the myotome, and also a type has been used where the collection of anterior cornual nuclei embedded in protoplasm seems to arise from the myotome *en masse*. Both Balfour and Beard refer to Löwe's statement that the cells of this mass are, in part, of myotomic origin, and remark that this statement is a "gratuitous assumption." Surely it is likewise a gratuitous assumption to derive them from the neural tube. If they have wandered out from the neural tube, what are they? And why do they wander out?

With regard to the question of protoplasmic continuity! We were very interested in the question of fixation and felt that, whatever certain *fixed* specimens showed, there is a living connection between the myotome and the neural tube. Observing very many embryos in the course of fixation, we found that with a very great variety of fixatives the invariable response was violent contractions of the embryo extending over quite an appreciable interval of time, and this sometimes after preliminary chloretone treatment.

Despite such violent contractions during fixation, we have found obvious continuity between the neural tube and myotome at very early stages. Our observations confirm those of Graham Kerr, Hensen and others on this point.

Urodele material in our possession for which we are indebted to Dr Landacre of Ohio State University show unbroken lines of yolk and pigment passing between the neural tube and myotome, and by this fact leave no doubt of absolute protoplasmic connection. To our knowledge continuity, by virtue of a study of the disposition of the mitachondrial elements, has not been urged previously.

What is the nature of this connection? It is surely a protoplasmic pathway between the neural tube and the myotome. Graham Kerr (fig. 12, *a*, *b*, *c*) says "The nerve trunk is lengthened out and externally is continued into the muscle cell of the myotome." There is no doubt he means motor nerve trunk (*m.n.r.*). There is no proof that there is a differentiated motor nerve trunk at so early a stage, meaning by nerve trunk the *effector* axon. Again, muscle cells have not been seen at this stage. The cells to which he refers are at that time primitive types in the process of differentiation, and many changes are going to take place on the inner wall of the myotome before there are seen muscle cells differentiated out of the cells of which he speaks.

Assuming for the moment that these connections could be motor nerves, then it would mean that the neuroblast itself has differentiated in ontogeny at a time antedating any known differentiation of neuroblasts, and, furthermore, that the *effector-expressor* mechanism has differentiated long before the *ganglion-receptor* differentiation in association with which it undoubtedly arose in phylogeny. We will return to this question in the next section of our paper dealing with migration.

THE MIGRATION OF NERVE CELLS

The phenomenon of cell migration is accepted by all as being of fundamental importance in questions of development. The movements of blood cells, of phagocytic cells of various kinds, of mesenchyme cells are real, that these cells do move is amply shown by the examination of living embryos. Dr Sabin's work on the chick and the Clarks' on the tadpole are illustrative of the phenomenon.

It is not surprising therefore, in the face of a familiar parallel instance, that practically all writers on the origin and development of the peripheral nervous system have given expression to some conception of migration in the case of the nerve cell, perhaps the most extreme example being that of Neumayer, who speaks of cells passing out of the neural tube and then being "fetched back" again. No one has actually seen the migration of a nerve cell in its entirety in the living embryo and without some selective method of intra-vitam staining such demonstration would be almost impossible.

What do we mean by migration of the nerve cell?

If a movement of the complete cell occurs from a place x to a place y, then it is legitimate to speak of the migration of that cell in its entirety. Evidence of such migration requires to a certain extent that those structures

in the vicinity of the cell, by which we determine the relative alteration in position of the cell, should be fixed in position and in time. Again to show migration of a cell, in the sense in which we speak, requires that we demonstrate a movement of the whole cell and, since we ourselves in an extensive study of embryos, have never been able to define cell boundaries in their entirety, we hold that despite the suggestive appearances offered, the question is not proved either way from purely histological methods.

To illustrate our meaning, let us refer to figs. 3 and 7. It could be granted, for the sake of argument, that the nuclei are moving either towards or away from the neural tube, but, if the protoplasm under the influence of any particular nucleus is, on the one hand, fixed in relation to the neural tube and, on the other hand, to the myotome, the cell as a whole does *not* move with reference to these structures if those relations are maintained. *The nucleus may move however*, and we believe it does do so. It is conceivable further, that, without any alteration in the relative position of the cell, the nucleus may be in earlier periods in relation to the myotome and in later periods become absorbed into the neural tube. Such an interpretation is justified not only from the figures of Selachian embryos we here produce, but also from His' own figures despite the fact that they bear only the faintest resemblance to the embryos they are designated to depict.

Assuming, then, that the nuclei may migrate, is there any other way in which the nuclei of motor neuroblasts may find themselves in the ventral horn of the neural tube and yet be primarily extraneural in origin?

There are three possible lines of approach to this problem.

(1) The examination of a close series of embryos.

(2) The experimental method.

(3) By the observation of living embryos in such a manner as Drs Sabin and Clark have done for cells of other types.

THE SERIAL METHOD

This method is recognised by all to have its serious limitations, and for this reason has been supplanted at various times by newer fashions, such as the culture method and the experimental method. These in their turn have limitations just as serious if not more so.

The serial method seems to us to give an almost complete answer to this problem and yet with many observers has not only failed, but has led to erroneous interpretations for the reason that an elementary law of topographical survey has been disregarded.

The fundamental principle in surveying is that the "base line" or "datum line," from which subsequent measurements are taken in order to determine the relative position of objects, must be *fixed in space*. No surveyor takes the shore line of a beach which is continually silting up for this purpose. For, should he do so, his map would soon have little value. The "datum line"

which has been used by embryologists consciously or otherwise, has been the external limiting membrane and so any cells within the membrane have been stated to come from the neural tube itself.

If we take any embryo in early stages we find, as His depicts in his fig. 39 (fig. 5 of this paper), blood forming cells (*Bd.*) just outside the external limiting membrane—in brief, the rudiment of a branch of the anterior spinal artery. We find this artery takes a constant position. We refer readers to current text-books of embryology, to His' own work, to Hensen's pictures and others. We reproduce different embryonic stages of this vessel, figs. 12, 13 and 14, showing its constancy with relation to adjacent structures.

The order of structures from within outwards is:

(1) The original neural tube which is in most cases clearly distinguishable.

(2) Commissural fibres running from the posterior horn to the anterior horn of the opposite side.

(3) The blood vessel in question.

(4) The motor nuclei and also that which formed at the same time the included portion of the neural crest designated by Balfour as the commissure of the neural crest.

The longitudinal connection between successive sensory segments has become included at the same time and so is laid the foundation for the columns of Goll and Burdach. The transference of the posterior root from a dorsal to a lateral position in the cord, so puzzling to Balfour, is explained by the increasing prominence of these longitudinal columns.

This fact of *inclusion into the neural tube* is borne out by the studies of Kolliker upon reptilian and avian forms, where the process of *inclusion* is incomplete and motor cells lie extra-neurally even in the adult. That these cells are somatic motor cells is shown by the later work of Sterzi and is indicated in fig. 14, of a toad fish embryo, here provided. It seems reasonable to assume, concerning these pictures, that the differentiation of motor neuroblasts is relatively later in these particular animals.

We are now in a position to discuss the observations of Ramón y Cajal. The earliest stage in which he could obtain a result with his method of staining was a 72 hour chick. His figure is reproduced as fig. 15.

Upon our hypothesis the neuroblast designated as motor is already included. Cajal's picture gives explanation of the true status of the so-called "motor nerve fibres" of Graham Kerr, previously referred to. These may well be the protoplasmic bridges in which the *intercalated axones* (*sensorium* of Huxley) are formed, and at this stage these axones, as depicted by Cajal, are becoming completely included into the neural tube.

As motor neuroblasts are differentiated before the 72 hour stage is reached, and before a silver reaction can be secured, it is obvious that Cajal's work can give us no certain information concerning their origin.

So far we have demonstrated the fact that motor neuroblasts and other cells may become incorporated into the neural tube without having to call

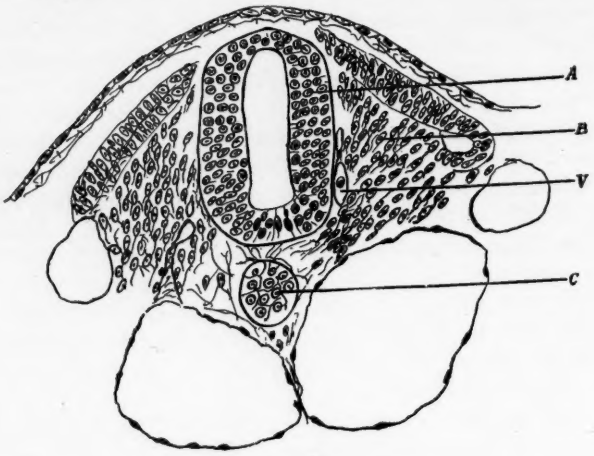


Fig. 11.

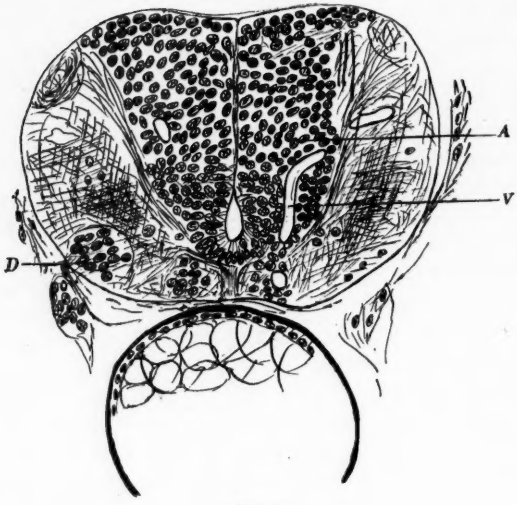


Fig. 12.

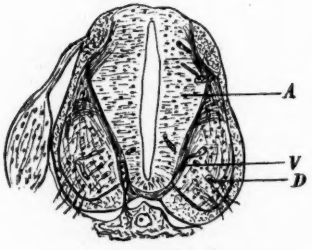


Fig. 13.

in the aid of complete cell migration as a factor. We are nevertheless in accord with Ariens Kappers that neurobiotaxis is a real thing. Ariens Kappers has shown that the position of the motor nuclei in the medulla oblongata is in

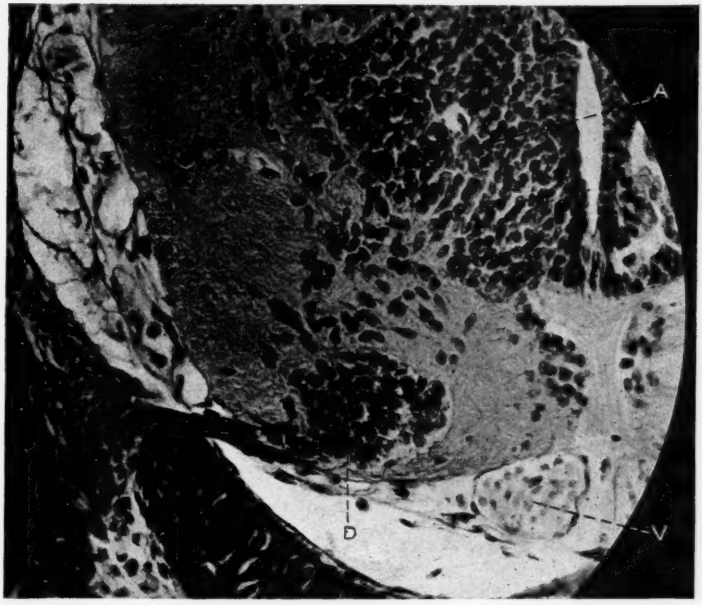


Fig. 14.

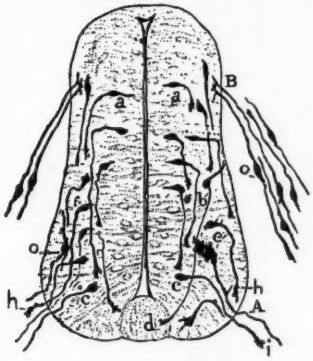


Fig. 15.

great part determined by the particular sensory tracts that predominate. If such is the case and motor nuclei are attracted thereby, centripetal rather than centrifugal movements on the part of motor neuroblasts should be

expected. Consequently the inclusion of the motor cells of the anterior cornu in the neural tube forms the most striking verification of the neurobiotactic conception of Kappers.

We have so far dealt with the problem of the origin of the motor neuroblast from fixed serially sectioned material and from the physiological side.

EVIDENCE FROM THE EXPERIMENTAL METHOD OF APPROACH

A considerable volume of experimental work has been done on the problem of the behaviour of nerve cells and the questions of development generally. But that the experimental method gives results capable of antagonistic explanations is shown by the anomalous findings in the works of Shorey and Harrison. It is instructive at the same time to compare the experimental results of Kuntz and Eric Muller on the origin of the sympathetic system.

At Wood's Hole, during the summer, we subjected the early developing tadpole of the Bull Frog to treatment with ·7–·8 per cent. NaCl as suggested to us by Dr Streeter.

Stockard from the experimental side, and Murk Jansen from the clinical side have shown that, if embryos are exposed to certain influences at definite times in development, certain definite defects or arrests in development follow. Anencephalia and amyelia are examples of such *developmental arrests*.

In these particular experiments, careful histological examination showed that we were not successful in producing complete absence of the neural tube, i.e., complete anencephalia and amyelia. However, many cases histologically approached very closely this condition. In these embryos with defective neural tubes the myotomes developed and became fused with their fellows of the opposite side. Collections of ganglionic cells also developed ventral to, and, in many places, separated from, the neural tube in the substance of the fused myotomes. These embryos were capable of "vortex" movements. We reproduce fig. 16, a type of such specimens, which are certainly confirmatory of our histological investigation in normal embryos; for if neuroblasts develop from the substance of the myotome, such an extra-neural situation of motor cells is to be anticipated where the neural tube is incomplete.

Sherrington states that the anencephalic foetus suckles at the breast. Accurate information concerning the activities of such monsters is difficult to secure, but in Cincinnati we received first-hand information concerning the behaviour of an anencephalic monster. The mother gave birth to twins, of which the second was an anencephalic monster. The doctor and nurse placed it on one side and attended to the other child. Shortly afterwards the nurse called the doctor's attention to the fact that the monster was moving its limbs about and gasping for breath. A cast of the head of this foetus, preserved at the Cincinnati hospital, leaves no doubt as to its anencephalic character.

The explanation of these "reflex" phenomena is not yet apparent, but as in the tadpoles discussed, may well be bound up with the phenomenon of

the inclusion of extra-neural elements into the neural tube. They are certainly inexplicable upon the His hypothesis. It is hoped that when the attention of obstetricians is called to these facts, still more precise evidence will be forthcoming concerning the neuro-physiology of these curious monsters.

The remarks of Andral concerning teratomata are of great interest: "The progress, which has recently been made in the cultivation of embryology and comparative anatomy, has taught us that the greater number of the organs are much more independent of each other in their respective formation, than was for a long time supposed; and that consequently any arrest in the development of one organ, but seldom necessarily produces a similar arrest in the development of others. For instance, we now know that the nerves may

Fig. 16.

be perfectly developed independently of the existence of the brain or spinal cord; as has been abundantly proved in several cases of anencephalia and amyelia. It appears that the nerves are primarily formed in those organs, which it is their office to connect with the centres of the nervous system; and that they do not unite with these centres for a considerable time after their first rudiments are perceptible. Where these organs are deficient, the nerves are likewise deficient; so that the existence of the nerves depends much more on the development of the organ which they are destined to supply, than on that of the nerve centres.

M. Serres has recorded a remarkable illustration of this fact in the case of a monster with two brains and a single body in which case there were only

two pneumogastrics found, arising one from the external side of each brain. In this case there were only two pneumogastric nerves, because there was only a single pulmonary and digestive apparatus for them to supply. In other cases on the contrary, which M. Serres has cited, when these organs were double, and the brain single, there were two sets of nerves destined for the two sets of organs" (1832).

It is consequently clear that the revival of so ancient a conception can scarcely be regarded as revolutionary. The most modern views concerning developmental teratology and neurology found support in very salient evidence almost a century ago.

In conclusion we desire to express our deep sense of indebtedness to Professor Grafton Elliot Smith for his generous advice and assistance in the preparation of this paper and to Professor Frederic T. Lewis of Harvard for placing the Minot Embryological Collection at our disposal during our stay in Boston.

DESCRIPTION OF FIGURES

A. Neural tube.
B. Inner wall of myotome.
C. Notochord.
D. Ventral ganglion.
E. Dorsal ganglion.
V. Vessel.

Figs. 1, 2, 3, 6, 7, see text.

Figs. 4 and 5. (His' figs. 38 and 39.) *Pristiurus*-embryo von 4½ mm. Länge. Neuroblasten aus der Markfläche hervorbrechend. *M.* Myotomozellen. *Bd.* Bindegewebszellen.

Fig. 8. (His' fig. 40.) *Pristiurus* von 6 mm. Länge. Gruppe von Neuroblasten, ihre Fortsätze an eine vordere Wurzel abgebend. Gekreuzer Verlauf der Fasern, die zum Ramus dorsalis und die zum R. ventralis gehen. *C.* Gruppe von Bindegewebszellen an der Stelle, wo später ein Blutgefäss liegt.

Fig. 9. (His' fig. 43.) *Pristiurus*-embryo von 8 mm. Länge. Randschnitt eines Wurzelstämmchens. Das von einer kleinen Neuroblastengruppe ausgehende Stämmchen endet in kurzer Entfernung vom Mark schräg abgeschnitten. *Bd.* längs und quer gelagerte Bindegewebszellen in dessen Umgebung. Bei *C.* ein capillares Längsgefäss.

Fig. 10. (His' fig. 44.) *Pristiurus*-embryo von 14 mm. Länge. Der Randschleier ist deutlicher ausgebildet, die Intermediärschicht vorhanden. Die vordere Wurzel zeigt einen cylindrischen axialen Strang, von einzelnen Bindegewebszellen umlagert. Innerhalb des Marks sind einige Fasern durch den Randschleier hindurch bis zur Intermediärschicht verfolgbar, andere treten schon vorher aus der Schnitt-fläche heraus. Bei dieser und bei der vorigen Figur sind die reifen Neuroblasten an ihren hellen Kernen erkennbar. Bei *C.* das Längegefäss.

Fig. 11. Chick No. 2. 49 hours, sect. 7. 2. 4, illustrating the position of the anterior spinal artery in an earlier stage than fig. 12.

Fig. 12. Toad fish embryo, No. 638, sect. 13. 2. 7, to illustrate the branch of the anterior spinal artery and the outlying group of motor cells.

Fig. 13. Pig embryo 8 mm.

Fig. 14. Toad fish embryo, to illustrate laterally placed motor ganglion. Note position of blood vessel entering the neural tube.

Fig. 15. (Ramón y Cajal's fig. 7 *a*.) Coupe de la moëlle d'embryon du poulet au 3^{e} jour de l'incubation.

Fig. 16. Bull frog embryo after treatment with ·8 per cent. NaCl.

LITERATURE CITED

ANDRAL, G. (1832). *A Treatise on Pathological Anatomy*, translated from the French by Richard Townsend and Wm. West. New York, Samuel Wood and Sons, 261, Pearl St.

BALFOUR, F. M. (1876). "The development of elasmobranch fishes." *Journ. of Anat. and Physiol.* vols. X and XI.

BEARD, J. (1888). "Morphological Studies. II. The development of the peripheral nervous system of vertebrates. Part 1. Elasmobranchii and Aves." *Quart. Journ. Micr. Sci.* vol. 29.

CLARK, E. R. (1912). "Further observations on living growing lymphatics: their relation to the mesenchyme cells." *Amer. Journ. of Anat.* vol. XIII, No. 3.

HARRISON, R. G. (1907). "Observations on the living developing nerve fibre." *Anat. Rec.* vol. I, No. 5.

HELD, H. (1909). *Die Entwickelung des Nervengewebes bei den Wirbelthieren.* Barth, Leipzig.

HENSEN, V. (1903). *Die Entwickelungsmechanik der Nervenbahnen im Embryo der Säugetiere.* Kiel and Leipzig.

HIS, W. (1889). "Die Neuroblasten und deren Entstehung im Embryonalen Mark." *Abh. sachs. Gesell. Wiss.* Leipzig. Math.-phys. Cl., Bd. 15, No. 4.

KERR, GRAHAM J. (1902–3). "The development of Lepidosiren paradoxa." *Quart. Journ. Micr. Sci.* vol. XLVI.

KOLLIKER, A. (1902). "Ueber die oberflächlichen Nervenkerne im Marke der Vögel und Reptilien." *Zeitschrift f. wissen. Zool.* LXXII. 1.

KUNTZ, ALBERT and BATESON, O. V. (1920). "Experimental observations on the histogenesis of the sympathetic trunks in the chick." *J. Comp. Neur.* vol. XXXII.

MULLER, ERIC and INGVAR, SVEN, (1921). "Ueber den Ursprung des Sympathicus bei den Amphibien." *Upsala Läkäref. förh.* Ny följd. Bd. XXVI, H. 5–6.

NEAL, H. V. (1903). "The development of the ventral nerves in Selachii. 1. Spinal ventral nerves." *Mark Anniversary Volume*, Article XV.

—— (1921). "Nerve and plasmodesma." *J. of Comp. Neur.* vol. XXXIII, No. 1.

NEUMAYER, L. "Entwickelungsgeschichte der Wirbelthiere." *Hertwig*, vol. II, Teil 3.

PARKER, G. H. (1918). "The elementary nervous system." *Monographs on Experimental Biology.* J. B. Lippincott & Co., Philadelphia.

PATON, S. (1908). "The reactions of the vertebrate embryo to stimulation and the association changes in the nervous system." *Mitt. aus der Zool. Stat. zu Neapel*, Bd. 18.

RAMÓN Y CAJAL (1890). "A quelle époque apparaissent les expansions des cellules nerveuses de la moëlle épinière du poulet?" *Anat. Anz.* vol. V, p. 638.

SABIN, F. R. (1917). "Origin and development of the primitive vessels of the chick and the pig." Contributions to Embryology, vol. VI. *Carnegie Instit. Wash. Pub.* 226.

SCHAPER, A. (1897). "Die frühesten Differenzirungsvorgänge im Centralnervensystem." *Archiv f. Entwick. mech. der Organismen*, Bd. V, Heft 1.

SHERRINGTON, C. S. *Schäfer's Text-book of Physiology.*

SHOREY, M. S. (1909). "The effect of the destruction of peripheral areas on the differentiation of the neuroblasts." *Journ. of Exper. Zoology*, vol. VII, No. 1.

STERZI, ANDREA I. (1904). "I gruppi cellulari periferici della midolla spinale dei rettili." *Inst. Anat. della Regia Univ. di Pisa.*

WINTREBERT, M. P. (1904). "Sur l'existence d'une irritabilité excito-matrice primitive indépendante des voies nerveuses chez les embryons ciliés des Batraciens." *Comptes Rendus de la Soc. de Biol.* vol. LVII.

ABSENCE OF THE LENS OCCURRING IN THE HUMAN EMBRYO

By IDA C. MANN, M.B., B.S.

From the Department of Anatomy and Embryology, St Mary's Hospital.

The subject of this communication is a human embryo (one of Professor Frazer's collection) which, as far as I know, is unique in that it shows failure of development of both lenses: the optic cups are of normal size and the rest of the embryo shows no evident malformation with the exception of the state of the brain shortly noticed below.

After sectioning, the embryo measured 8·64 mm. It was compared with a normal 13 mm. human embryo (measuring 8·67 mm. after sectioning) with regard to its general development and they were found to have reached the same stage as evidenced by the condition of the submaxillary outgrowth (just appearing in both) and the situation of the posterior nares. The embryo was not in good histological condition and the sections were considerably fissured. The thin walls of the intracranial portion of the central nervous system were much folded, as might be expected in an embryo not in perfect condition, but in addition to this—without going into details—there is, I think, clear evidence of some dilatation of the cavities. The cerebral vesicles are clearly recognisable in their normal hinder portions, but do not appear to have grown in front so that they cannot be definitely marked off from the telencephalon. In spite of these peculiarities the general structure of the substance of the brain appears to be that normal for the stage.

The condition of the eye is the same on both sides. The optic cups occupy their normal position on the side of the head. Their invagination and differentiation have proceeded normally, but the choroidal fissure, which does not extend quite into the optic stalk, has not yet closed, whereas in the normal 13 mm. embryo it has closed except for a notch at the pupillary margin. The hyaloid vessel is present and is well developed and full of blood. It breaks up into numerous blood spaces in the pupil and these drain into scattered channels in the surrounding mesoderm and into a vessel larger than normal running in the line of the cleft outside the optic cup. There is no lens whatever, and the only suggestion of it is the presence of a small blunt-pointed epithelial projection from the deep layer of the surface ectoderm almost opposite the centre of the pupil. This may represent an abortive lens thickening which has failed to differentiate.

The case is interesting both on account of the confirmatory evidence it offers on the subject of independent differentiation of the optic cup (shown experimentally by Lewis, Spemann and others) and also as throwing some light on the clinical controversy as to the possibility of the occurrence of congenital aphakia in an otherwise normal eye. Rabl has described an Amblyostoma embryo which showed unilateral failure of development of the lens, but there was also extensive failure of other ectodermal structures. A few cases in man have been reported clinically, but were not verified by microscopical examination and were generally associated with microphthalmos.

REFERENCES

Adams (1915). "Congenital aphakia with microcornea." *Ophth. Rec. Chicago*, vol. xxiv. p. 581.

Bach. "Pathol. Anat. Studien über verschiedene Missbildungen des Auges." *Archiv für Ophth.* vol. 45, Pt. 1, p. 1.

Baker (1887). "Congenital aphakia." *New York Med. Journ.* vol. xlvi. p. 595.

Cherryholmes (1902). "Congenital aphakia with microphthalmos." *Ophth. Rec. Chicago*, vol. xi. p. 198.

Hardy (1915). "Congenital aphakia." *Ophth. Rec. Chicago*, vol. xxiv. p. 347.

von Kupffer (1896). *Verhandl. der Anat. Gesellsch. auf der zehnten Versammlung in Berlin.*

Lewis, W. H. "Expt. Study of Devel. of Eye in Amphibia." *Amer. Journ. Anat.* vol. iii. p. 505, 1904 and vol. v. p. 9, 1906.

Ochi (1919). "Experimental Study of Histogenesis of eye abnorm. in chick embryos." *Brit. Journ. Ophth.* vol. iii. p. 433.

Rabl (1898). "Ueber den Bau u. Entwicklung der Linse." *Zeitschr. f. wiss. Zool.* vol. 63.

Sherer (1915). "Congenital aphakia, a clinical report." *Journ. Missouri Med. Ass. St Louis*, vol. xii. p. 478.

Spemann (1901). *Anat. Anz.* vol. 19, suppl. p. 61.

Wiegels, H. (1900). *Arch. f. Ophth.* vol. 50, p. 369.

A SUGGESTION AS TO THE CAUSE OF THE ASPERMATIC CONDITION OF THE IMPERFECTLY DESCENDED TESTIS

By F. A. E. CREW, M.D., D.Sc.

(*Paper from the Animal Breeding Research Department, The University, Edinburgh.*)

In all Vertebrates the testes are developed in contact with the ventral surface of the kidneys, behind the peritoneum covering the body-cavity. In some they remain permanently in this situation, but it is characteristic of the majority of mammals that during the course of development they leave their primitive lodgment and migrate posteriorly and ventrally to the terminal periphery where they protrude at the surface of the body-wall. This protrusion constitutes the scrotum which varies in character from that of a pair of small ill-defined slightly elevated areas to that of a capacious, definite, pedunculated sac.

A survey of the Vertebrates will show that the testes in different cases are found in positions which mark the stages in a complete migration from the primitive position near the kidneys to the peripheral scrotum. It will also be seen that the scrotal situation of the testis is characteristic of the more impulsively active mammals. In the case of the human, in whom the migration has been most thoroughly studied, it provides a very complete example of the manner in which ontogeny repeats and condenses phylogeny in whole or in part.

There is much diversity of opinion as to the exact mechanism of the migration and it is probable therefore that not one but several factors are involved. The process possibly may be explained thus. Mechanical forces resulting from the changing methods of progression compelled the dense, compact, suspended testis to pass from the primitive position towards the inguinal region of the abdominal cavity (Woodland). There it naturally came to lie in the line of the lymph-sinuses described by Sabin. With increasing impulsiveness of movement and with increased intra-abdominal pressure consequent upon the development of the diaphragm, the testis was forced along the lymph-track so that it came to occupy a sub-integumental position in the groin (Bramann, Eberth, Keith). Here the testis found itself in a situation which in several ways was different from the interior of the abdomen and it was obliged to adapt itself to the new conditions. But, owing to its decreased mobility and to the injurious effects of active flexion of the thigh upon the abdomen, it suffered repeated attacks of inflammation. The local peritoneum with the mesorchium became involved in this inflammation with the result that ad-

hesions and bands were produced. The overlying skin became thinned and stretched. Then further increase of impulsive activity and of intra-abdominal pressure produced a hernia of the testis. So the scrotum and the inguinal fold could have been produced. The position of the testis was equivalent to the sub-integumental one in the groin but the organ was now secure from injury by muscular movements since its mobility had been restored.

This process would be repeated in every generation until at last variation succeeded modification, or, by adaptation, the migration became incorporated in the life-processes of the individual and anticipated by the development of a mechanism which would produce the descent of the testis during foetal life.

"Originally, the descent of the testes did not occur until sexual maturity in all cases, but in many Mammalia (e.g. Marsupials, Ungulates, Carnivores, Primates), the process has gradually become shifted backwards ontogenetically to earlier periods, so that the formation of the scrotum takes place independently in the embryo in the form of the external genital folds." WIEDERSHEIM.

In the modern mammals in which the migration occurs, the testis is united to a mammary area—supra-pubic, inguinal, perineal, or scrotal, at first by the inguinal fold and later by the gubernaculum—the canal-former, the guide of the testis—which is attached by its upper end to the Wolffian duct, the epididymis, and at the point where the globus minor and vas deferens meet, and by its lower end to the subcutaneous tissues in the groin, the scrotum, the root of the penis, and on the pubis.

The gubernaculum is an actively growing mass of fibro-muscular tissue which, starting from the muscular stratum in the mesorchium and inguinal fold in the inguinal fossa, invades the abdominal wall, every layer of which it carries with it as a prolongation within the scrotum. Upon the peritoneum thus drawn down the testis is dragged like a log upon a sledge. The gubernaculum forms the inguinal canal by the growth of its wedge-shaped end along the line of the lymph-sinuses, The canal is formed before the testis passes.

The final situation of the testis is decided in great part by the relative development of the different gubernacular insertions.

There is no physiological reason why the testis should not leave its primitive position. It does not stand in the same relation to the general economy of the individual as do the other organs of the body. It belongs to the race rather than to the individual, for though there cannot be an actual isolation yet there is distinctly an apartness of the germ-cells and the body is but the carrier of the testes. The migration to the periphery does not disturb the general economy for this reason and just as reproduction itself consists of a separating off of a portion of the organism so the organs of reproduction become separated, in consequence of their migration, from the viscera which belong entirely to the individual.

It is too difficult to conceive that the migration has imparted any advantage to the organism: the process bears no great relation to either advantage o

disadvantage, though the scrotal position would appear to be one much exposed to danger, for the ease with which the scrotum is attacked and the devastating effects of contusion of the testes make of this region a veritable Achilles' heel.

"...there remain many unsolved problems. Take, as an instance, the descent of the testis in the Mammalia. Neither direct nor indirect equilibration accounts for this. We cannot consider it an adaptive change, since there seems no way in which the production of sperm-cells, internally carried on in a bird, is made external by adjustment to the changed requirements of mammalian life. Nor can we ascribe it to the survival of the fittest; for it is incredible that any mammal was over-advantaged in the struggle for life by this changed position of these organs. Contrariwise, the removal of them from a place of safety to a place of danger would seem to be negatived by natural selection. Nor can we regard the transposition as a concomitant of re-equilibration, since it can hardly be due to some change in the general physiological balance." HERBERT SPENCER.

There certainly appears to be no compensatory physiological advantage offering benefits which outweigh the physical disadvantage and it would seem that the migration is, as suggested, but the inevitable concomitant of some other constant feature of the animal's existence, and that it has not arisen in relation to ulterior ends.

A study of the conditions in which the testis fails to complete its migration will show that the testis has become so modified that while it will function perfectly when within the scrotum, it is incapable of producing spermatozoa when situated elsewhere. This would indicate that the conditions within the scrotum are different from those of the interior of the abdominal cavity.

"The descent of that testicle is very slow which is not complete before birth, often requiring years for that purpose; and it sometimes never reaches the scrotum, especially the lower part of it. There is oftener, I believe, an inequality in the situation of the two testicles than is commonly imagined; and I am of the opinion that the lowest is the more vigorous, having taken the lead readily, and come to its place at once.

"It is not easy to ascertain the cause of this failure in the descent of the testicle; but I am inclined to suspect that the fault originates in the testicles themselves. This, however, is certain, that the testicle, which has completed its descent is the largest, which is more evident in the quadruped than in the human subject; as in these we can have the opportunity of examining the parts when we please, and can determine how small in comparison with the other that testicle is which has exceeded the usual time of coming down; it never descends so low as the other.

"When one or both testicles remain through life in the belly, I believe that they are exceedingly imperfect, and probably incapable of performing their natural function, and that this imperfection prevents the disposition for descent from taking place." JOHN HUNTER.

"Arrest of descent is commonly regarded as a symptom of arrest of testicular development. John Hunter regarded arrested descent of the testicle as due to an imperfection in its development; all recent observations support his opinion." KEITH.

"It is commonly believed that the imperfection of an undescended testicle is due to its failure to reach the scrotum. This I believe to be an error. An undescended testis fails to reach the scrotum because of its imperfection." BLAND-SUTTON.

In spite of the great weight of these opinions it is difficult to accept them without question since it is generally understood that the testis plays but a passive rôle in the migratory process. Imperfection of the local peritoneum during the development of the inguinal fold and mesorchium; of the gubernaculum; of the inguinal canal; or of the scrotum, these conditions also must lead to imperfect descent.

The long mesorchium may allow the testis to hang too freely in the abdominal cavity; there may be a deficiency or abnormality of the upper attachment of the gubernaculum; intra-uterine peritonitis may have caused adhesions which limit the mobility of the testis; shortness of the vas deferens and of the blood-vessels, though more likely to be an effect, may also be a cause of imperfect descent; the inguinal canal may be imperfectly formed or the scrotum ill-developed so that passage thereinto may be hindered. Over-action of the cremaster may be another possible cause, for in infants and children the action of this muscle occasionally draws the testicle up even beyond the external ring. Murard records a case in which the testis periodically disappeared into the abdominal cavity.

Imperfection of the testis most certainly can be a potent cause of its non-descent, but unless it is of such a size or of such a shape that it cannot pass along the passage prepared for it, surely the fault must lie with the powers, or with the passage, but not with the passenger.

"It is certain that in the majority of cases the imperfectly or abnormally descended testicle is functionless, at any rate as regards spermatogenesis. But though the function of spermatogenesis is absent, that of producing the internal secretion necessary for the development of the secondary sexual characters of the male is generally, but not always, carried out. That the function of spermatogenesis is lost is shown by the fact that such persons are unable to beget offspring and is also confirmed by the histological examination of retained testes after removal.

"In rare cases the spermatogenetic function is not lost, even when there is a double imperfect descent with very small testes, or when both organs are arrested within the abdominal cavity; this has been proved both by the presence of normal tubules and active spermatozoa, and also by the fact that these persons have proved capable of procreation. Many examples of this are recorded in medical literature. There is, however, evidence that those in which spermatogenesis is normally carried out are young men mostly under thirty years of age. In men over this age the imperfectly descended testis is nearly always functionless. In the majority of cases under thirty the spermatogenetic function is absent and the proportion of functional organs is probably small." TURNER, P.

"After careful observations extending over many years I only once found spermatozoa in an undescended testis." BLAND-SUTTON.

"It is not rare to find spermatozoa in testicles which have remained in the lower part of the inguinal canal, but in those in the upper part, and in those taken from the abdomen, this is exceptional." HOBDAY.

"In mammals the testes fail at times to pass through the inguinal canal, and, in consequence of their retention in the body-cavity, the germ-cells fail to develop. On the other hand, the interstitial cells of the testis develop normally. Cryptorchid individuals show the normal secondary sexual characters of their species." MORGAN.

M'Fadyean, who examined a series of twenty-five imperfectly descended testes for Hobday, found that out of fourteen from the abdominal cavity, only two contained spermatozoa, and that of eleven from the inguinal canal—three being from the upper part—only five were capable of functioning. Gurlt failed to find spermatozoa in testes removed from the abdomen; Wesche found that testes from the inguinal canal were capable of producing functional spermatozoa; Paugoué records the case of a stallion in which both testes were undescended yet who sired many colts of which, however, five suffered from the same condition; Dollar states the opinion that testes retained within the abdomen contain degenerate spermatozoa or none at all.

As a result of the examination of a series of imperfectly descended testes from the horse, placed at my disposal by the courtesy of Mr Wm. Brown of the Veterinary Department, Marischal College, I am able to demonstrate the fact that the nearer the testis comes to lie to the normal scrotal position, the more likely it is that functional spermatozoa will be found therein. Testes removed from the lower part of the inguinal canal, though smaller in size than the normal and inclined to be of an unusual shape, are in the majority of cases imperfectly functional; testes removed from the abdominal cavity, so far as my experience goes, are invariably the seat of tumour growth, benign or malignant, even in the case of two-year old horses; testes removed from the upper part of the canal are usually atrophic and normal spermatozoa can be found therein only very exceptionally.

Russell Howard records that of twenty-seven cases of malignant disease of the testis, nine had occurred in imperfectly descended glands.

It would seem that when the testis occupies its normal position in the scrotum, the conditions are such that the activities of the other component tissues of the gland are restrained by the dominating activity of the germinal epithelium, but that when the testis is brought to rest in an abnormal situation, the function of spermatogenesis being in abeyance, the other tissues of the gonad take on an uncontrolled growth.

Griffiths, in an experimental investigation on dogs, found that when the testes of the puppy were replaced within the abdominal cavity they developed normally up to the time of puberty but that they never produced spermatozoa, and that when the testes of grown dogs were similarly replaced within the abdomen they invariably atrophied and never remained functional.

In those mammals in which the testis periodically passes into a scrotum

during the breeding period, it is found that they are spermatic only when in the scrotum, and aspermatic when within the abdomen.

To explain the relation between imperfect descent and imperfect functioning there are two theories: one, that the imperfection in functioning is the cause of the imperfect descent, the other, that it is the result. The first postulates that there is some abnormality of the germinal epithelium which prevents the normal development and migration. If this is so, then obviously no operative treatment can possibly restore the spermatogenic function. The second explanation is that full growth and development of the testis up to the time of puberty is possible in an abnormal situation, but that at the time when the final stages of spermatogenesis should occur, the abnormal situation reacts upon the testis in some way so that these stages cannot occur and atrophy of the testis ensues while various pathological processes easily attack the gland leading to degeneration and tumour growth. If the fault lies with the situation and not with the testis, if the absence of the spermatogenic function is the result of the malposition, then the operation of Orchidopexy should restore this function. It may be accepted that if an immature imperfectly descended testis is secured within the scrotum without operative injury it will complete its development and function normally.

But if the final stages of spermatogenesis are effected in one situation, the scrotum, and not in another, the abdominal cavity, there must exist some great difference between these two situations.

Such a difference does exist. It is that the temperature within the tunica vaginalis is appreciably lower than that within the general abdominal cavity.

It was known to John Hunter that the temperature of the body is not the same throughout; he demonstrated this fact by several most ingenious experiments on mice and dogs. But more recently, and with much more critical methods, Benedict and Slack have shown that there is a temperature gradient of some 5° C. between the temperature of the abdominal cavity and that of the surface of the body. The temperature rises in proportion to the depth to which the thermometer is inserted until at 6–8 cms. a constant temperature is reached.

The testis within the scrotum is not exposed to the same temperature as that of the primitive position within the abdomen. Moreover, a consideration of the peculiar structure of the scrotum will show that this is a very specialised area of body surface extremely well equipped with a mechanism for local temperature-regulation.

The scrotum is a pouch composed of skin and the dartos tunic. It is divided on its surface by a median raphe into two lateral portions. The skin is very thin, of a brownish colour, and is usually thrown into rugae. It is well supplied with sebaceous follicles, the secretion of which has a peculiar odour, and is beset with thinly scattered crisp hairs, the roots of which are visible through the skin.

The dartos tunic is a thin layer of non-striated muscle, continuous around the base of the scrotum with the two layers of superficial fascia of the groin and of the perineum. It sends inwards a septum which extends between the median raphe and the under surface of the penis, as far as its root, and divides the scrotum into two cavities for the testes. It is closely applied to the skin externally and is connected with the subjacent parts by a delicate areolar tissue upon which it glides with the greatest facility. There is no fat in this areolar tissue; the scrotum is fat-free even in the fattest of entire animals. But in the castrate the scrotum is loaded with fat and the butcher's test for prime beasts is the amount of fat in the scrotum.

Klaatsch has shown that in many mammals the site of the future scrotum is marked out by a certain area of skin, evident both by its naked-eye and microscopic characters. White and Martin state that in cases of ectopy in which, owing to an over-development of an insertion of the gubernaculum other than the usual, the testis comes to occupy a position beneath the skin of the perineum, the overlying skin assumes the peculiar characters of that of the scrotum.

The appearance of the scrotum varies with different conditions of atmospheric temperature. Under the influence of warmth, and in the debilitated and old, it is elongated and flaccid; under the influence of cold, and in the young and robust, it is short, corrugated, and closely applied to the testes. The amount of surface exposed is controlled by the action of the dartos.

The scrotum stands well away from the body and is in an area where transpiration is well marked. The temperature within it is not only considerably lower than that within the general cavity but its regulation is controlled by a most efficient mechanism.

That the scrotum itself, by reason of its specialised structure, is concerned in the functioning of the testis is shown by the results of certain diseases in which the scrotal integument becomes very much thickened and inelastic, as in *Elephantiasis arabum*, for the testes become deformed and atrophied. The testis within such a scrotum is in a situation equivalent in many ways to the interior of the abdominal cavity.

John Hunter, Ashworth, Child, Marshall, Reamur, Semper, Graham Kerr, Bles, Spallanzani, Meek, Turner, C. L., and many others have produced considerable evidence which goes to show that reproductive activity is intimately related to external temperature in the case of the lower orders. In the fish, for example, it has been shown that the beginning of the annual decline in temperature is contemporaneous with the seasonal volumetric increase in the testes of the Perch, and that the beginning of the seasonal decrease in the testes is contemporaneous with the beginning of the seasonal rise in the temperature. It can be accepted that growth and reproduction vary in length and periodicity with temperature and though, undoubtedly, other factors also are concerned, it is sufficient to recognise that temperature itself is a factor.

In the case of the testiconda it is possible that some of the pharyngeal derivatives, such as the thymus, the function of which is not definitely known, control the activities of the testes throughout the individual's whole lifetime, whereas in the case of the mammals whose testes normally migrate to the scrotal position, the action of the internal secretion of this gland has become restricted to inhibiting the too active development of the testis up to the time of puberty, when the body is sufficiently grown so that it can entertain the demands of spermatogenesis. The thymus is so situated that it can readily appreciate changes in the environmental temperature and its intimate association with the activities of the testes is acknowledged. In the case of the scrotal testis, the situation is such that the optimum temperature for spermatogenesis can be maintained throughout the year because of the development of the local temperature-regulating mechanism. The thymus becomes unnecessary after puberty and consequently atrophies.

But be it as it may, the fact remains that the testes of the testiconda, and of the other Vertebrates in which their normal position is abdominal, have never been required to adapt themselves to function in a situation in which the local temperature is markedly different to that of the general abdominal cavity. This also applies to the ovaries of all the Vertebrates. They are so organised as to function quite satisfactorily in an intra-abdominal situation, and so far as can be ascertained, should an ovary come to occupy an ectopic position, it does not produce functional ova. This great distinction between ovary and testis in the case of the higher mammals has a very direct bearing upon the question of hermaphroditism in the human and renders the postnatal reversal of the sex-organisation, such as occurs in the case of the Amphibians, for example, utterly impossible.

Since the capacity for functioning within a scrotum has been of the nature of an adaptation, it is not extraordinary that exceptionally an imperfectly descended testis should produce functional spermatozoa.

SUMMARY

1. In the more impulsively active mammals the testis leaves its primitive position to pass into the scrotum. The process of migration has been shifted back ontogenetically so that now the formation of the inguinal canal and of the scrotum occurs in anticipation of the descent of the testis. The process bears no great relation to either advantage or disadvantage; it is but the inevitable concomitant of other constant features of the animal's existence and has not arisen in relation to ulterior ends.

2. The testis has become adapted to function in a situation, the conditions of which are markedly different from those of the general abdominal cavity. It can no longer function in the primitive position. The great difference between the two situations is one of temperature. The temperature within the tunica vaginalis is considerably lower than that within the abdomen. The scrotum

is so constructed that it is exceedingly well equipped with a temperature-regulating mechanism. The final stages of spermatogenesis occur at a certain optimum temperature which is that within the scrotum and not that within the abdominal cavity.

3. The imperfectly descended testis is aspermatic because the temperature of the abnormal position is not that at which the final stages of spermatogenesis occur.

BIBLIOGRAPHY

ANNANDALE. *See* MARSHALL.
ASHWORTH. *See* MARSHALL.
BENEDICT, F. C. and SLACK, E. P. (1902). *Public. Carnegie Instit.* No. 153.
BLAND-SUTTON, J. *See* HOBDAY.
BLES. *See* MARSHALL.
BRAMANN (1884). *Arch. f. Anat.*
CHILD. *See* MARSHALL.
DOLLAR, J. A. W. (1902). *The Practice of Veterinary Surgery.* Edinburgh.
EBERTH (1904). *Die männlich. Geschlechtsorgane.* G. Fischer, Jena.
ECCLES, MCADAM (1903). *The Imperfectly Descended Testicle.* London.
GRIFFITHS. *See* WHITE and MARTIN.
GURLT. *See* DOLLAR.
HART, BERRY (1910). *Journ. Anat. and Physiol.* vol. 43, p. 244; vol. 44, p. 4.
HARTUNG, E. (1875). *Ueber einen Fall von* Mamma accessoria. Erlangen.
HOBDAY, F. T. G. (1914). *Castration and Ovariotomy.* Edinburgh.
HOWARD (1907). *Practitioner.*
HUNTER, JOHN (1837). *Works,* vol. 4. Palmer edit.
KEITH, A. (1921). *Human Embryology and Morphology.* London.
KINGSLEY, J. S. (1919). *Comparative Anatomy of Vertebrates.* London.
KLAATSCH (1890). *Morph. Jahrb.* vol. 16.
LOCKWOOD, C. B. *See* BERRY HART.
MARSHALL, F. H. A. (1910). *Physiology of Reproduction.* London.
MEEK, A. (1920). *Nature,* vol. 106, No. 2669, December 23rd.
MIGHON and PORTE (1920). *Lyon. Chir.,* Nov.–Dec.
MORGAN, T. H. (1902). *Public. Carnegie Instit.* No. 285.
MURARD (1919). *Lyon. Chir.* No. 16.
OWEN, R. (1866). *Comparative Anatomy and Physiology of Vertebrates.* London
PAUGOUÉ. *See* DOLLAR.
REAMUR. *See* MARSHALL.
SABIN. *See* BERRY HART.
SPALLANZANI. *See* MARSHALL.
SPENCER, H. (1866). *Principles of Biology,* vol. 1, p. 573.
TURNER, C. L. (1919). *Journ. Morphol.* vol. 32, No. 3.
TURNER, P. (1919). *Inguinal Hernia.* London.
WESCHE. *See* DOLLAR.
WHITE and MARTIN. *Genito-urinary Surgery.* Lippincott edit.
WIEDERSHEIM (1906). *Vergleichen. Anatomie d. Wirbeltiere.* Jena
WOODLAND (1903). *Proc. Zool. Soc. Lond.* p. 319.

ODONTOLOGICAL ESSAYS

By L. BOLK, M.D.,

Director of the Anatomical Institute of the University of Amsterdam.

FOURTH ESSAY

ON THE RELATION BETWEEN REPTILIAN AND MAMMALIAN TEETH

Of the many varied problems of Odontology, no one is more interesting and fascinating than the origin of the complicated tooth form found in Mammals. The simplest mammalian tooth is believed not to be primitive but to have been evolved from a very simple prototype. Furthermore, this prototype must be sought for in the Reptiles as they are generally regarded as the ancestors of the Mammals. If this be granted the problem resolves itself into tracing the derivation of the complicated mammalian tooth from the simpler ancestral reptilian form.

The solution of the problem demands in the first place a recognition of the features of the type form from which the mammalian tooth is derived; and in the second place a knowledge of the changes which this type form has undergone whereby the complicated tooth of the mammal is the result.

The literature on the subject evidences that as regards the first point opinion is practically unanimous. In spite of the unanimous support accorded to it I hope to prove this popular opinion to be incorrect.

The second point involves a question which is far from easy to answer. Many morphologists have attempted to do so, but opinion is notably diverse and no two investigators are in complete agreement thereon. Writers on the subject may be classified into groups according to the principles upon which their views are founded.

Some hold that the mammalian tooth results from the concrescence of a varying number of simple conical reptilian teeth, a single cusp of the former corresponding to a complete tooth of the latter.

This, the *concrescence theory*, implies that a mammalian tooth is homologous with several reptilian teeth. Many odontologists accept this theory although their application of the principle varies considerably.

Others hold an entirely opposite opinion and consider that every mammalian tooth, even the most complicated, represents a single reptilian tooth: the originally simple conical crown becoming complicated by the superaddition of new cusps. The special nature of the food and the relative position of the tooth in the jaw are regarded as the stimuli determining the growth of new cusps. This view is known as the *differentiation theory*.

It is not my intention to review the two theories methodically and in chronological order or to summarise the different principles assigned to them. This would entail a criticism of the opinions and assertions of other investigators. As previously mentioned in a foregoing essay I wish to avoid a polemical discussion as far as possible. My chief purpose is to communicate certain new and hitherto unknown facts and further to propound the views at which I have arrived as the result of my observations. It is my intention in this essay to present my personal views as to the relationship existing between reptilian and mammalian teeth.

In so doing the meaning of the developmental phenomena—the enamel-niche and the enamel-septum—described in the second essay will become clear. As a consequence the present paper is more theoretical in character than its predecessors.

A summary of the essential points of my theory regarding the relationship existing between reptilian and mammalian teeth will prove instructive as such a summary will facilitate the understanding of my general argument. Further, a knowledge of my views will render the reader familiar with the value I attach to certain definite phenomena and will acquaint him with the conclusions at which I have arrived.

The principal points of my theory can be summarised in the following theses:

Thesis 1. The reptilian tooth from which that of the mammals evolved was not of a simple conical or styloid form, as is the current opinion, but possessed a crown with three cusps; a main cone, with anterior and posterior accessory cusps upon its slopes. The three cusps are placed in an antero-posterior linear series. (Hypothesis of Triconodonty.)

Thesis 2. Every mammalian tooth, with certain exceptions presently to be mentioned, is homologous with two reptilian teeth. The outer half of the mammalian tooth with the series of buccal cusps represents one of these teeth, the inner half with the series of lingual cusps represents the other. These two parts of the mammalian tooth may be distinguished as: the *protomere* (buccal part) and the *deuteromere* (lingual part). (Hypothesis of Dimery.)

Thesis 3. The mammalian tooth was not evolved from two reptilian teeth by means of a real coalescence of two separate and independent elements, but in consequence of a concentration of the anlage of two reptilian teeth. (Hypothesis of Concentration.)

Thesis 4. The elements of a mammalian set of teeth are all morphologically and genetically equivalent. The terms monocuspidate and multicuspidate possess only a descriptive-anatomical value and do not indicate morphogenetic differences. The differences in shape exhibited by the teeth are solely of a quantitative nature. The anlage of every tooth possesses the potentiality of developing all the cusps found in the most complicated tooth of the set. Complication is to be regarded as completeness. Simplicity of a tooth is explained by the fact, that the anlage of a tooth develops its potentialities in a more or less incomplete manner. (Hypothesis of Equivalency.)

These theses form the basis of my theory regarding the relationship between reptilian and mammalian teeth. The theory may be termed the "Dimer theory." In discussing these theses the terms protomere and deuteromere are now intelligible.

In the second thesis I have alluded to certain exceptions. This thesis is not applicable to the grinding teeth of the elephant and in all probability not to the teeth of the extinct Multituberculata. A future essay will be specially devoted to the results of an inquiry into the ontogenesis of the teeth of Elephas, the result of the study of the foetus of an *Elephas Africanus*, which I had the good fortune to acquire. I have made very interesting observations regarding the elephant's odonto-genesis, which in some points differs radically from that of other mammals, and which renders the morphology of the teeth of Probiscidea intelligible.

I will now discuss the question as to the type of reptilian tooth from which the mammalian tooth is evolved. The opinion of authorities upon this point is, as I have already remarked, unanimous, the form of the primitive tooth being invariably regarded as conical or styloid. For instance Marett Tims[1], in a communication upon this subject, expresses himself as follows: "The type of primitive tooth was the haplodont or simple cone; and the object of the present paper is an endeavour to trace the evolution of the complex crowns of the mammalian cheek-teeth from such a pattern" (*l.c.* p. 133). I will restrict myself to this one quotation from an English author.

I may commence with a criticism of the arguments advanced in favour of this view. Undoubtedly a conical tooth is the simplest imaginable. It is also true that many reptiles are endowed with a set of these very simple teeth. Finally, mammals may be provided with a purely haplodont dentition. These facts are all well known, but that they afford a reliable basis to the assertion, that the conical or styloid tooth is the primitive type from which that of mammals must be derived is questionable. From my point of view the assertion is untrue and I will endeavour to establish the ground of my disbelief.

If the shapes of the teeth of a large number of reptiles be examined, it will be found that only in a minority of these vertebrates do the teeth possess a conical or styloid form. This simple form must therefore be regarded as exceptional. In most cases, the teeth of reptiles are compressed from side to side and present sharp edges. The pattern of the teeth depends largely on the character of the food and on the development of the jaws. The latter factor is of no small importance.

That the conical teeth of the Crocodilia represent the prototype from which the complicated tooth of the mammals is to be derived is the current view. For instance, Osborn[2] expresses himself as follows: "The principle of growth was the regular addition of new parts to the simple cone." Is it beyond all reasonable doubt, that the teeth of Crocodilia are in reality primitive? Is

[1] "The evolution of the teeth in the Mammalia." *Journ. of Anat. and Phys.* vol. XXXVII, 1903.
[2] *American Naturalist*, 1888.

it not possible that the conical teeth are not primitive forms at all, but are simplified forms evolved from the commoner type of tooth compressed from side to side and provided with sharp edges? This question is fundamental, and its solution must be the starting point of any theory dealing not only with the relationship between the teeth of the reptiles and those of the mammals, but also with the respective dentitions of the two vertebrate groups. Authoritative views regarding this question are remarkable for their absence in the literature on the subject and the real value of the dogma that the styloid tooth is the prototype of the mammalian tooth has never been properly estimated. This I will endeavour to do as briefly as possible.

That certain mammals, namely the Odontoceti, are provided with a purely haplodont dentition is a well known fact. According to the commonly accepted view, this haplodont set of teeth is not primitive, but the simple conical teeth in these mammals have been acquired as an adaptation to the function of the very elongated jaws, being most suitable organs for seizing the prey. In jaws with such a function a large number of sharp conical teeth is obviously a very efficacious arrangement for piercing and retaining the prey. The investigations of Kükenthal prove that, not only are the styloid teeth of Odontoceti secondary formations, but enlighten us as to the manner in which the simplification of the elements of this dentition has occurred. The process was mainly the result of considerable elongation of the jaws. That a similar explanation of the dentition of the Crocodilia has never been propounded is somewhat surprising. In these animals, as in Odontoceti, the jaws are markedly elongated and are thereby adapted for seizing the prey and retaining it. To consider the conical teeth of Odontoceti as simplified forms while those of the Crocodilia are to be regarded as primitive does not seem to be a logical conclusion. I have endeavoured to collect sufficient data to enable me to form a conclusion on this most interesting question by studying the development of the teeth of *Crocodilus porosus*. My observations seem to have a most important bearing on the problem, as I have been able to establish the fact, that the elements comprising the first row of teeth appearing in the young embryo of this reptile are by no means of a conical form, as are those in the newly born animal, but are compressed from side to side, as is the case in the functional teeth of most of the Lacertilia. These small teeth, however, never cut the gums and become functional, they atrophy and disappear before the embryo is full grown. One of my assistants made an elaborate investigation of the development of the teeth of reptiles and has confirmed this fact[1].

This observation justifies the conclusion that the Crocodilia have origin from an ancestral form provided with compressed sharp edged teeth resembling those in the majority of reptiles. My observations therefore do not allow me to accept the current opinion as to the value of the Crocodilian tooth as a prototype from which the mammalian tooth is to be derived, as this tooth,

[1] M. Woerdeman. "Beiträge zur Entwicklungsgeschichte von Zähnen und Gebiss der Reptilien." *Archiv für mikroskopische Anatomie*, vol. 92, 1919.

like the tooth in the Odontoceti is apparently the result of a secondary simplification.

There is a noteworthy difference, however, as to the manner in which the Odontoceti and the Crocodilia have acquired their respective haplodont dentitions. Kükenthal has demonstrated that the young embryo of Odontoceti possesses complicated teeth and at a later stage these teeth cleave; as a final result, one originally complicated tooth gives rise to a very restricted number of styloid teeth. In Crocodilia on the other hand, a set of complicated teeth which do not cut the gums appears and these are succeeded by a second set of styloid teeth. It is obvious that this difference in origin of the haplodont teeth in Odontoceti and Crocodilia is closely correlated with the diphyodonty of the mammals and the polyphyodonty of the reptiles.

The assertion that the prototype from which the mammalian tooth took origin was styloid may now, I think, be considered as based on insufficient evidence. Further, it must be kept in mind that the assertion is not the outcome of observations or deductions but is consequent on the hypothesis that every tubercle of the mammalian tooth corresponds to a reptilian tooth. This was the dogmatic basis of the concrescence theory of Röse and Kükenthal.

Thesis 1 contains both a denial of the truth of this dogma and my own point of view, namely, that the mammalian tooth is evolved from a tricuspid reptilian tooth, with a main middle cone and two side cones, and not from a styloid tooth. I shall now state my reasons for taking this view.

One of these has already been stated, namely, that such tricuspid teeth are found in many reptiles whereas the styloid form occurs as an exception only and as a result of adaptation to the elongation of the jaws.

The matter may be viewed from another standpoint as evidence regarding the form of the teeth in the more primitive mammals may be gleaned from Palaeontology. The American palaeontologist Osborn is undoubtedly the greatest authority on, and possesses a most extensive knowledge of, the teeth of the mesozoic mammals. Cope, who shares responsibility with Osborn for the well known tritubercular theory, presents in the first chapter of his book, *The Evolution of Mammalian Teeth*[1], several reproductions of the jaws of primitive mammals. The more primitive of these is the Upper Triassic Microconodon and Dromatherium, two genera still possessing molars with imperfect division of the fangs, a purely reptilian character. The crown of the molars of Dromatherium is not conical at all but "narrow and lofty, the general pattern of the crown consisting of a single main cone with a high anterior and a lower posterior accessory cusp upon its slopes." As regards Microconodon the author states (*l.c.* p. 21), "the molars have that regular tricuspid division of the crown, which is first observed in the genus Amphilestes of the English lower Jurassic, and characterises a large number of the Jurassic mammals."

Judging from the figures of Jurassic mammals reproduced by the author, tricuspidity is the prevalent form. The two accessory tubercles are not always strongly developed, and in these cases one would be inclined to believe that

[1] New York, London, 1907.

they represent simplified forms. This is, however, rarely met with as, for example, in the lower jaw of the Stylodon, reproduced by the author (*l.c.* p. 28). Cope himself deduces the tritubercular tooth—the elementary type of his odontological system—from a triconic predecessor.

Palaeontology therefore affords no support to the opinion that the prototype of the mammalian tooth is styloid.

Osborn admits this as he represents the evolution of the tritubercular type in the following manner (*l.c.* p. 39).

I. *Haplodont Type.* A simple conical crown. *This type has not as yet been discovered among the primitive mammals.*

II. *Triconodont Type.* The crown elongated and trifid, with one central cone and two distinct lateral cones. The fang is double. Example: Triconodon.

III. *Tritubercular Type.*

This scheme is practically an admission that Osborn regards a haplodont dentition in the primitive mammal as purely hypothetical, the type consisting of a crown with three cones placed in a row representing the earliest known form. That this form has been inherited from reptilian ancestors is a justifiable assumption. It is a tooth form often met with in Cynodontia, extinct reptiles which are closely related to mammals.

Such are my reasons for assuming that the prototype of the mammalian tooth is triconic. As far as Osborn's scheme is concerned it is a matter of small moment whether the primitive mammalian tooth is to be regarded as haplodont or tricuspidate, where the latter form is regarded as transitional, and whether this tricuspidate type has been transmitted from reptiles to the primitive mammals, or has been secondarily acquired by the latter. This remark also holds good if Osborn's tritubercular theory be accepted, but it is an entirely different matter should the mammalian tooth result from a process of concrescence as is my contention. Should the prototype from which the mammalian tooth developed by concrescence be styloid, as is the general view, every cusp of a mammalian tooth will correspond to one reptilian tooth. If, as I maintain, the prototype be tricuspid, then a group of cusps, disposed in a row, will correspond to one reptilian tooth and the number of elements taking part in the formation of a mammalian tooth will be considerably lessened.

Granting the truth of the latter view the concrescence theory is reduced to a simpler form while the origin of the teeth and their processes of development become less complicated. Further several phenomena which do not fall in line with the concrescence theory are now explicable.

Before the further consideration of the process of concrescence, I wish to draw attention to a phenomenon which is directly associated with my view concerning the fundamental nature of the mammalian tooth.

In the heterodont dentition of mammals the teeth have not all attained the same degree of development. Especially is this the case with the incisors

and canines, which exhibit the least differentiation. It is noteworthy, however, that the so-called monocuspidate teeth are in reality provided with three cusps. The three cusps vary in the extent of their development. In the case of the canine, the central cusp as compared with the two accessory cusps is usually the largest. Moreover the stage of development attained by the accessory cusps varies considerably in different individuals of the same species. In the case of the incisors on the other hand, the central tubercule is sometimes the broadest, sometimes the smallest, or the three tubercles may be equal in size; the last condition being the most frequent. This difference in degree of development of the three cusps observable in mammals, can also be detected in the teeth of reptiles, as is shown in fig. 97 in which parts of the dentition of *Tupinambus nigropunctatus* are represented. The intermaxillary teeth are shown in the top figure, each tooth possessing three cusps of equal size. The lower figure represents the hinder teeth which also possess three cusps, the central being the largest. That tricuspidity is a fundamental property of the

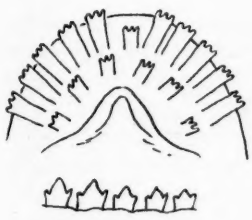


Fig. 97.

Fig. 98.

Fig. 99.

Fig. 100.

incisors, is demonstrated by a frontal section through such a tooth (fig. 98), whereby it is apparent that these cusps are not due to a local thickening of the enamel layer only, the dentine also taking part in their formation. This proves that the presence of the three cusps is a result of the growth activity of the tooth-papilla, for were this not the case the limit of the dentine would present a straight edge.

Special attention must be drawn to the fact that neither tricuspidity of the crown of incisors and canines in mammals, nor that of the teeth in reptiles, is caused by a concrescence of three adjoining but originally independent small teeth. Scales often exhibit three cusps; hairs are also often trifid consisting of one main and two accessory hairlets, and the tricuspidity under discussion is to be regarded as a similar phenomenon.

This primary property of the mammalian tooth, inherited from the reptilian tooth, controls—as will be shown in a later essay—the further differentiation of the mammalian tooth, and is the fundamental character in the pattern of

even the most complicated tooth. This character is conserved most purely in those teeth whose function corresponds most nearly to that of the teeth of reptiles, namely the incisors and canines, which are chiefly concerned in seizing and retaining the prey. This is elucidated by the following facts. A tricuspid form is often distinctly recognisable in the incisors and canines of Carnivora and Primates, as is demonstrated by the following figures. Fig. 99 represents the incisors of the milk-set of a *Felis leo*, fig. 100 the permanent incisors of *Canis lupus*. There are differences in detail, but both figures clearly show the tricuspid form of these teeth.

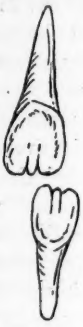


Fig. 101.

As an example of Primate dentition the crown of the human incisor, before it has been subject to use, is tricuspid, this being the case in the lower as well as in the upper jaw. "In recently erupted teeth, the thin cutting edge presents three slight tubercles, which soon wear down and disappear apparently by use" (Tomes, *Dental Anatomy*, p. 9). This is also true for the Primates generally. In this connection certain facts are worthy of note. In the case of the human tooth the three tubercles are equal in size. This is not always the case in other Primates, and it is remarkable that when reduction occurs it is always the central tubercle which suffers. This is evidenced by fig. 101, a reproduction of I_1, and I_2, of *Semnopithecus maurus*, as seen from the lingual side. The central tubercle is in this case the smallest. The reduction may sometimes lead to complete disappearance. This process can be easily followed in the genus Cebus, as shown in fig. 102, representing three upper medial incisors of *Cebus capucinus*, in (*a*) the tubercle is very small, in (*b*) it is absent, a notch and furrow indicating the seat of its disappearance, whereas in (*c*) the crown is partly split, on account of a still further increase in depth of the notch.

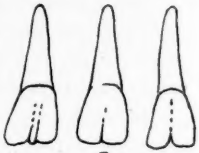


Fig. 102.

The disappearance of the central tubercle explains the splitting and duplication of the incisors, a not at all uncommon phenomenon. In a further essay, where I hope to deal with the causation of supernumerary teeth, I shall include such variations under the title *schizogenetic*.

That tricuspidity is a fundamental character of the incisors, is proved by the fact, first demonstrated by Margitol[1] as early as 1883, and subsequently confirmed by Schwalbe[2], that the crown of the incisors of permanent teeth in man, develops from three enamel tubercles, which originally separate, soon unite with one another. This fact makes the formation of crowns as shown in fig. 102 intelligible. The central tubercle in the medial incisors of Primates is, as has already been pointed out, in a condition of reduction. If this tubercle undergoes complete reduction, the lateral tubercles will unite; this will occur at a somewhat late stage of development, when they have already acquired

[1] *Journ. de l'Anat. et de Phys.* 1883, p. 59.
[2] *Morphologische Arbeiten*, vol. III, p. 491.

a certain altitude and as a consequence the crown will be more or less deeply incised.

So far the hypothesis formulated in Thesis I has not been elucidated and the next question concerns the morphological relationship between the triconodont prototype and the more complicated mammalian tooth. The answer to this is found in the same thesis, and I shall now set down the facts and considerations by which I was led to formulate it.

From what has been stated above it is evident, that, in my opinion, the prototype from which the mammalian tooth is derived corresponds to a phase in the Cope-Osborn tritubercular theory and so far we are on common ground. Cope and Osborn formulated their scheme as a result of palaeontological research. Their principal conclusion was that, as a result of further evolution, the central or main cusp, the so-called "protoconus" moved lingually in the upper, and buccally in the lower jaw. In this way the tritubercular tooth with the triangular crown was developed, the base being situated buccally in the upper, and lingually in the lower, jaw. This theory has but few supporters; the embryological researches of Woodward, Marett Tims and Tucker have proved the theory untenable. Gregory, originally a supporter of this part of the Cope-Osborn theory, rejected it in a later essay[1].

Although the embryological investigations of Woodward, Marett Tims and others have shown the fallacy of the Cope-Osborn theory, these investigators do not arrive at any definite conclusion as a result of their positive inductive reasonings. I venture to suggest that the embryological investigation explained and discussed in the second of these essays sheds a new light on the phylogeny of the mammalian tooth. In order to make the matter clear it will be advisable to recapitulate the essential points and descriptions recorded therein. This can be done most conveniently by means of a scheme showing the structure of the dental lamina and the enamel-organ as completely as possible (fig. 103). Especial attention must be drawn to the fact that this scheme is not hypothetical, but is the result of observations fully dealt with in the same essay. On the other hand I must confess that the investigator can but seldom hit upon the particular phase in the development of the enamel-organ, showing clearly and completely all the relations of the details in the scheme as they are represented.

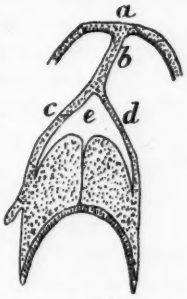


Fig. 103.

The scheme may be shortly described as follows. From the external epithelium of the mouth (*a*), a lamina (*b*), the "dental lamina" as it is usually termed, arises; this I designate the general dental lamina to distinguish it from others. This general dental lamina has a double connection to the enamel-organ. The real dental lamina is joined to the lingual side of the enamel-organ. This junction I term the "internal enamel-strand" (*c*). The second junction

[1] *Bull. Amer. Museum of Nat. Hist.* vol. xxxv, p. 239, 1916.

extends from the buccal side of the general dental lamina to the buccal side of the enamel-organ. This I term the "lateral enamel-strand" (*d*). These two bands and the upper surface of the enamel-organ enclose a canal—the enamel-canal (*e*). As this canal is closed behind at an earlier stage, a niche-like space "the enamel-niche" is formed. The way in which this niche develops and the enamel-canal is formed, have been discussed in detail in the second essay.

At an early stage of development a septum subdivides the enamel-organ into two halves, a buccal and a lingual. This I distinguish as the enamel-septum. It comes into being as the result of the development of two centres of pulp formation, one situated in the buccal and the other in the lingual half. Where the enamel-septum is attached to the external epithelium of the enamel-organ, the surface is often retracted, and thus a deepening, which I term the "enamel-navel," is formed. In the organ itself the enamel-septum is continuous with the layer of intermediate cells.

This description applies to what may be termed an ideal scheme of a fully developed enamel-organ. Further developmental details are given in my second essay.

The outstanding morphological characteristic of the enamel-organ is obvious. The complete toothgerm is in reality a duplicate organ, the two components of which lie side by side in a bucco-lingual direction. This is evidenced both by the double connection of the enamel-organ with the epithelial lamina from which the teeth are developed and by the two centres of pulp formation. It was pointed out in my second essay that the enamel-septum does not develop secondarily by an ingrowth of the external epithelium, but is a result of the formation of pulp derived from two centres, a lingual and a buccal. At an early stage the septum consists of undifferentiated cells disposed in the middle of the enamel-organ. These cells assuming a somewhat different form to those of the reticulum—as appears from some of the figures reproduced in the second essay—proves that the septum is essentially something more than a mere undifferentiated cell mass. An additional proof is provided by the fact that in some Marsupials blood-vessels enter into the septum from the outside.

The double nature of the toothgerm is evidenced not only by the system of "enamel bands" (an external and an internal) and by the structure and differentiation of the enamel-organ, but further by a third and no less important feature, namely, the layer of ameloblastic cells. This layer demonstrates the double nature of the toothgerm in two ways. Ahrens[1] has made the most important observation, that at a very early stage of development, the layer of ameloblastic cells is separated into buccal and lingual parts, and the elements of the enamel-septum between the two appear to be continuous with the tissue of the papilla. In this stage there is therefore no continuity between the ameloblast layers of the buccal and the lingual halves of the enamel-organ.

Thus the double nature of the toothgerm is proved by the enamel bands,

[1] *Die Entwicklung der menschlichen Zähne.* Habilitationsschrift, Wiesbaden.

by the enamel pulp and by the ameloblastic layer; in short, by the three components of the enamel-organ.

The duplicity of the ameloblastic layer is made evident in still another way, in that the formation of enamel begins independently in the buccal and lingual halves of the enamel-organ.

This holds good not only for the multicuspidate teeth, but even for the monocuspidate, where the so-called *Tuberculum dentis*, arising from a separate centre on the lingual side of the papilla, becomes secondarily united to the main cusps on the buccal half.

As all the component parts of the toothgerm, viz. the lamina-system, the enamel-organ and the layer of ameloblasts are apparently composed of two parts, a lingual and a buccal, I would term the toothgerm a "dimeric" organ, each one of its two constituents containing the elements necessary for the "anlage" and development of a complete tooth.

Embryology drives us to the conclusion, that the mammalian tooth is a composite organ built up from two parts, each of which alone is capable of developing into a complete tooth. When it is realised that herein lies the essential difference between a toothgerm of a reptile and that of a mammal the great importance of this fact becomes obvious. A detailed study of the development of teeth in reptiles appeared in my third essay. I stated that in lower vertebrates there is no question of a double junction of the toothgerm with the dental lamina, there is no enamel-septum and the layer of ameloblasts is absolutely single. Thus the toothgerm of reptiles is a single organ as is also the tooth which is formed from it. I therefore term the reptilian tooth "monomerous" in contra-distinction to the dimerous mammalian tooth.

Some new terms may now be conveniently introduced. The toothgerm of mammals is a dimerous organ, composed of a buccal and a lingual half. These halves I shall term "Odontomeres." It is advisable to designate the odontomeres by separate names. In future I will refer to the buccal as the "Protomere," while the lingual odontomere will be termed the "Deuteromere." Why these terms have been chosen will be explained later.

The toothgerm of reptiles being monomerous, while that of mammals is dimerous, makes it clear that the dimery of the mammalian tooth is a property acquired in consequence of the manner in which the mammalian tooth evolved from that of the reptilian ancestor. The toothgerm of mammals is not homologous with that of reptiles, the former being homologous with two germs of the latter. The mammalian tooth evidently corresponds to two reptilian teeth, represented by the protomere and the deuteromere respectively.

Before drawing attention to certain characteristics of full-grown mammalian teeth, made intelligible by the dimerous nature of the tooth, enquiry may be made as to the conclusions that can be drawn by combining the first and second theses. (Hypotheses of Triconodonty and Dimery.)

According to the first thesis the reptilian tooth from which the mammalian is derived, was not monocuspidate but possessed three conules, a larger middle

conule and two accessory cusps, anterior and posterior respectively. It is obvious that if a mammalian tooth is formed by the fusion of two such elements, the fundamental type of the tooth must have six cusps. In this sexitubercular tooth the outer or buccal three cusps represent the protomere, the three inner or lingual cusps the deuteromere. In order to interpret the morphological value of the cusps correctly, it must be kept in mind that the middle cusp of each row is potentially the strongest, and is therefore the most important. These facts may be represented by a simple formula.

The typical protomere of the mammalian tooth possesses one main and two accessory cusps. As I shall distinguish the former by the letter *P*, and the accessory cusps by the numbers 1 and 2, the protomeric element of the tooth may be represented as

$$1\ P\ 2.$$

Similarly the deuteromere has a main cusp, which I shall distinguish by the letter *D*, and the two accessory cusps to be distinguished by the numbers 3 and 4. Thus the general structure of this part of the tooth may be indicated by

$$3\ D\ 4.$$

Therefore the symbols for the buccal row of cusps are $1\ P\ 2$, whereas those for the lingual row are $3\ D\ 4$. By combining the two a "crown-formula" may be constructed and accordingly the crown-formula of the type form of the mammalian tooth is expressed as

$$\frac{1\ P\ 2}{3\ D\ 4}.$$

The dividing line indicates the distinction between the protomerous and deuteromerous elements of the crown.

The use of crown-formulae greatly facilitates odontological description, as the pattern of a tooth is expressed in a very simple and suggestive manner. This is not the case when special terms are used, as for instance in the Cope-Osborn system. Furthermore crown-formulae may be used to distinguish the teeth of the milk from those of the permanent dentition, capital letters being used for the latter, small type for the former, e.g.

$$\frac{1\ p\ 2}{3\ d\ 4}$$

represents the crown-formula of a milk-tooth.

A cusp resulting from the fusion of two primitively independent cusps may be indicated by placing their symbols in brackets, e.g.

$$\left(\frac{P}{D}\right).$$

In order to demonstrate the usefulness of this system of crown-formulae, I intercalate a table demonstrating the formulae of the post-canine teeth in the upper jaw of Prosimiae, Platyrrhinae and Katharrhinae. I do not intend to discuss the contents of these tables, which will serve as examples only.

Further information regarding the morphological value of these tables may be obtained by consulting my *Odontologische Studien*, II. 128–181 (Gustav Fischer. Jena, 1914).

In this publication I have demonstrated that the main cusps of the protomere, ***P***, may, as the result of further differentiation, be subdivided into

Crown-formulae of the upper post-canine teeth of Primates.

	P_1	P_2	P_3	M_1	M_2	M_3
Tarsius	$\frac{1\ P\ 2}{}$	$\frac{1\ P\ 2}{D}$	$\frac{1\ P\ 2}{D}$	$\frac{1\ Pa\ Pp\ 2}{D}$	$\frac{Pa\ Pp}{D}$	$\frac{Pa\ Pp}{D}$
Stenops	$\frac{1\ P\ 2}{}$	$\frac{1\ P\ 2}{D\ 4}$	$\frac{1\ P\ 2}{3\ D\ 4}$	$\frac{1\ Pa\ Pp\ 2}{3\ D\ 4}$	$\frac{1\ Pa\ Pp\ 2}{3\ D\ 4}$	$\frac{1\ Pa\ Pp}{D\ 4}$
Nycticebus ...	$\frac{1\ P\ 2}{}$	$\frac{1\ P\ 2}{D}$	$\frac{1\ P\ 2}{D\ 4}$	$\frac{1\ Pa\ Pp\ 2}{D\ 4}$	$\frac{1\ Pa\ Pp}{D\ 4}$	$\frac{1\ Pa\ Pp}{D}$
Cheirogaleus ...	$\frac{1\ P\ 2}{}$	$\frac{1\ P\ 2}{}$	$\frac{1\ P\ 2}{D}$	$\frac{Pa\ Pp}{D\ 4}$	$\frac{Pa\ Pp}{D\ 4}$	$\frac{Pa\ Pp}{D}$
Galago	$\frac{1\ P\ 2}{}$	$\frac{1\ P\ 2}{D}$	$\frac{1\ Pa\ Pp\ 2}{3\ D\ 4}$	$\frac{1\ Pa\ Pp\ 2}{3\ D\ 4}$	$\frac{1\ Pa\ Pp\ 2}{3\ D\ 4}$	$\frac{1\ Pa\ Pp}{D\ 4}$
Hemigalago ...	$\frac{1\ P\ 2}{}$	$\frac{1\ P\ 2}{D}$	$\frac{1\ Pa\ Pp\ 2}{3\ D\ 4}$	$\frac{1\ Pa\ Pp\ 2}{3\ D\ 4}$	$\frac{1\ Pa\ Pp\ 2}{3\ D\ 4}$	$\frac{1\ Pa\ Pp}{3\ D\ 4}$
Avahis	—	$\frac{1\ P\ 2}{}$	$\frac{1\ P\ 2}{}$	$\frac{1\ Pa\ Pp\ 2}{3\ D\ 4}$	$\frac{1\ Pa\ Pp\ 2}{3\ D\ 4}$	$\frac{Pa\ Pp}{D}$
Propithecus ...	—	$\frac{1\ P\ 2}{}$	$\frac{1\ P\ 2}{D}$	$\frac{1\ Pa\ Pp\ 2}{3\ D\ 4}$	$\frac{1\ Pa\ Pp\ 2}{D\ 4}$	$\frac{Pa\ Pp}{D}$
Indris	—	$\frac{1\ P\ 2}{}$	$\frac{1\ P\ 2}{D}$	$\frac{1\ Pa\ Pp}{3\ D\ 4}$	$\frac{1\ Pa\ Pp}{D\ 4}$	$\frac{Pa\ Pp}{D\ 4}$
Lemur	$\frac{1\ P\ 2}{}$	$\frac{1\ P\ 2}{D}$	$\frac{1\ P\ 2}{D}$	$\frac{1\ Pa\ Pp}{D}$	$\frac{1\ Pa\ Pp}{D}$	$\frac{Pa\ Pp}{D}$
Hapale	$\frac{1\ P\ 2}{D}$	$\frac{1\ P\ 2}{D}$	$\frac{1\ P\ 2}{D}$	$\frac{Pa\ Pp}{D}$	$\frac{Pa\ Pp}{D}$	—
Chrysothrix ...	$\frac{1\ P\ 2}{D}$	$\frac{1\ P\ 2}{D}$	$\frac{1\ P\ 2}{D}$	$\frac{Pa\ Pp}{D\ 4}$	$\frac{Pa\ Pp}{D\ 4}$	$\frac{Pa}{D}$
Mycetes	$\frac{1\ P\ 2}{D}$	$\frac{1\ P\ 2}{D}$	$\frac{1\ P\ 2}{D\ 4}$	$\frac{1\ Pa\ Pp\ 2}{D\ 4}$	$\frac{1\ Pa\ Pp\ 2}{D\ 4}$	$\frac{Pa}{D}$
Cebus	$\frac{P}{D}$	$\frac{P}{D}$	$\frac{P}{D}$	$\frac{1\ Pa\ Pp\ 2}{D\ 4}$	$\frac{Pa\ Pp}{D\ 4}$	$\frac{Pa}{D}$
Ateles	$\frac{P}{D}$	$\frac{P}{D}$	$\frac{P}{D}$	$\frac{Pa\ Pp}{D\ 4}$	$\frac{Pa\ Pp}{D\ 4}$	$\frac{Pa}{D}$
Nyctipithecus ...	$\frac{P}{D}$	$\frac{P}{D}$	$\frac{1\ P\ 2}{D}$	$\frac{Pa\ Pp}{D\ 4}$	$\frac{Pa\ Pp}{D\ 4}$	$\frac{Pa}{D}$
Cercopithecidae	$\frac{P}{D}$	$\frac{P}{D}$	—	$\frac{Pa\ Pp}{D\ 4}$	$\frac{Pa\ Pp}{D\ 4}$	$\frac{Pa\ Pp}{D\ 4}$
Anthropoidae ...	$\frac{P}{D}$	$\frac{P}{D}$	—	$\frac{Pa\ Pp}{D\ 4}$	$\frac{Pa\ Pp}{D\ 4}$	$\frac{Pa\ Pp}{D\ 4}$
Homo	$\frac{P}{D}$	$\frac{P}{D}$	—	$\frac{Pa\ Pp}{D\ 4}$	$\frac{Pa\ Pp}{D\ 4}$	$\frac{Pa\ Pp}{D\ 4}$

two daughter-cusps, which I have distinguished as *Pa* and *Pp*, since they occupy anterior and posterior positions relatively to one another. This subdivision is characteristic of the molars, but may occur also as a rare exception in premolars, as, for example, in the genera Galago and Hemigalago.

This essay must convince the reader that I am no upholder of the theory that a mammalian tooth is homologous with a reptilian tooth and that the complicated structure of the former is to be interpreted as merely a reaction to its functional activities. At the same time I would urge that function is a factor of great importance in modelling the crown of the mammalian tooth. However, my views on this problem differ fundamentally from those generally held, in that I am of the opinion that every toothgerm possesses the potentiality of forming all the cusps present, in what may be termed the mammalian "standard tooth," namely, three cusps on the protomere and three cusps on the deuteromere. In my opinion the significance of function, as a factor influencing cusp formation, is that those cusps which are necessary to fit the tooth for the particular rôle it has to play in the general dentition are developed, the other cusps remaining latent. In other words, function exercises a selective influence in cusp-forming potentialities, some being stimulated while others are repressed. This view is the application of my hypothesis of a primary equivalency of all teeth composing a mammalian dentition.

My view as to the origin of the mammalian tooth is therefore intermediate between the pure differentiation theory and the pure concrescence theory, as will be set out in detail later. The manner in which I conceive the complicated nature of the mammalian tooth and its dimerous character came about must first be explained. With this object in view my third thesis, the hypothesis of concentration as I have designated it, must now be discussed.

In upholding the view that every mammalian tooth is homologous with two reptilian teeth, I am open to the accusation of supporting the concrescence theory. This, however, is not the case, as, according to this theory, a complicated mammalian tooth is formed by the concrescence of as many reptilian teeth as there are cusps in the crown of the tooth, each cusp representing a reptilian tooth. Against this view I bring two fundamental objections. In the first place a real concrescence of two or more elements situated in an antero-posterior direction has never been observed and has never been proved. Comparative anatomy and comparative embryology furnish no evidence whatever that such a concrescence has taken place as a preliminary stage for the evolution of the mammalian tooth, which is composite in a bucco-lingual direction only.

My second objection concerns the idea of "concrescence" itself. The notion the term concrescence conveys is, that two or more independent, disconnected organs are fused into one indivisible whole. A multiplicity becomes a unity. This notion of concrescence is either tacitly accepted or explicitly stated in odontological literature. In my opinion this notion is the weakest point in the concrescence theory, both in its actual form and in its various applications. In the first place, no observations have as yet been published, proving the appearance of a concrescence of two separate teeth into one tooth. It is true that developmental phenomena are described, which are interpreted as proving such a concrescence, but these cases are not conclusive, as the

phenomena can be explained in an entirely different way. Kükenthal in particular, a firm adherent of the concrescence theory, has published and given diagrams of a number of very interesting observations on the teeth of Cetaceae, which he regards as evidencing concrescence. These cases, which I will discuss later on, do not prove concrescence, but may be explained as stages of incomplete scission.

The dimerous tooth of the mammals is not, in my opinion, the result of a real concrescence of two originally independent teeth. Were this the case one would expect to find indications of it either in such reptiles as the Cynodontia which are considered to be the direct ancestral forms of the mammals—or in the triassic mammals. Such indications, however, are entirely wanting.

If the dimerous mammalian tooth is not the result of the concrescence of two reptilian teeth in a bucco-lingual direction, how is this type of tooth to be accounted for? To answer this question I must discuss in detail the process of development of reptilian teeth, and mention a few facts serving as a starting-point of the subject of the next essay, in which the relation between the dentitions of the reptiles and of the mammals will be considered. One of the chief differences between the dentitions of the reptiles and of the mammals, is that the former are polyphyodont, the latter diphyodont. In mammals there is but one succession of teeth, in reptiles on the contrary there is an indefinite number of successions. The intensity of this process varies greatly in reptiles; some forms exhibiting very intensive tooth-change, while in others the process happens but rarely. The duration of the existence of a tooth must therefore vary very considerably in the different reptiles. In both reptiles and mammals the teeth are formed by the so-called tooth-band. I may anticipate the subject-matter of my next essay, wherein its morphological nature will be described, by pointing out the general relation of the tooth-band to the teeth.

The potentiality of tooth-formation in the dental lamina of the reptiles is apparently concentrated in a larger or smaller number of circumscribed centra arranged in two rows. Such a centrum I call a "tooth-matrix." A tooth-matrix is a circumscribed mass of epithelial cells, surrounded by inactive epithelium. When the embryonic tooth-band has grown into the subjacent mesenchymatous tissue, the various tooth-matrices begin to function.

A survey of the development of the teeth of the reptiles may be given by the aid of the diagrams in fig. 104. The first diagram illustrates the dental lamina with a swelling at the free border, the first indication of a toothgerm. The tooth-band of reptiles shows in a particularly clear way a structure which can also be observed in mammals, but much less clearly and only for a comparatively short period. The tooth-band of reptiles is a fold derived from the surface-epithelium pushing its way into the subjacent mesenchymatous tissue. This band consists of two laminae, buccal and lingual, continuous with one another at its free or distal border. Both laminae are composed of cylindrical cells, continuous with the deep layer of cylindrical cells of the surface-epithelium. Intervening between the buccal or outer and lingual or

inner lamina of cylindrical cells, is a thin layer of more indifferent epithelium. From its commencement the toothgerm projects in a buccal direction, the tooth papilla pushing into it, as is shown in diagram 2. While the odontoblasts are being differentiated in the papilla and the ameloblasts, reticular cells and external epithelium are appearing in the enamel-organ, the toothgerm migrates to the buccal side of the tooth-band. As a result the originally free border of the tooth-band, in which the enamel-organ takes origin, reappears as is shown in diagram 3. Diagram 4 indicates a further stage of development. The enamel-organ has migrated surfacewards, i.e. towards the base of the dental lamina. The connection of the organ with the dental lamina is now entirely on the outer side of the tooth-band, and it seems as if the external epithelium of the enamel-organ takes origin from the buccal lamina of the tooth-band. The enamel-organ is, in fact, not completely closed; the reticular tissue is continuous with the tissue of indifferent cells between the outer and inner laminae of the tooth-band. In the meantime the formation of the dentine and enamel has commenced.

In its further development the tooth begins to push its way between the two laminae of the tooth-band, as may be seen in 5 and 6 (fig. 104). In

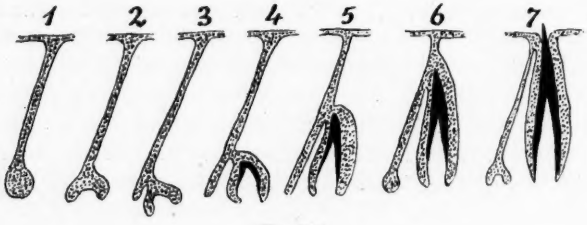


Fig. 104.

so doing the apex of the tooth is inclined towards the base of the dental lamina. As the attachment of the organ to the lamina is displaced towards its base, the tooth-band gradually re-acquires its original form. Finally the apex of the tooth reaches the surface as shown in 7 (fig. 104). Consequently the tooth does not really break through the surface epithelium as its apex appears between the two laminae of the tooth-band.

Such, in brief, is the story of events usually happening in reptiles. Variations do occur, but they can easily be explained as modifications of the generalised method of development.

It must be realised that the reptiles have in reality no free enamel-organs, and in addition this organ is incompletely closed, its reticular tissue remaining in continuity with the indifferent tissue between the two laminae of the tooth-band. In the next essay the manner of development of the teeth of the reptiles will be proved to be derived from that of the sharks, and it will then become evident that in this respect the Selachii and the Reptiles have much in

common. Further the morphological significance of the tooth-band will become intelligible.

Returning again to the diagrams in fig. 104, it will be noticed that when the enamel-organ has reached the surface, and the tooth-band has re-acquired its original shape, the free border of the latter begins to swell again at the same spot at which the first enamel-organ took origin. This is shown in diagram 6. The second toothgerm develops and behaves exactly like its predecessor. When the second tooth reaches the surface it pushes out and replaces the first.

From the above description I hope I have made it clear that the teeth of the reptiles are the products of a matrix. The tooth-band swells again and again at its free border, each new tooth as it is formed, migrates upwards towards the surface and replaces its predecessor. The enamel-organ of a replacing tooth does not take origin from the enamel-organ of its predecessor, but two succeeding teeth are formed independently of one another from one and the same matrix, situated in or near to the free border of the dental lamina. The relationship between a tooth and its successor is therefore not that of mother and child, but as that between two children of one mother, one born after the other.

In such manner a tooth-matrix produces a large number of teeth during the life span of the individual. I shall distinguish all teeth formed from one and the same matrix as a "tooth family" of which every individual succeeding tooth is regarded as a generation.

The number of matrices in the tooth-band of the reptiles varies in different genera, but this is, for the moment, a matter of minor importance. Of greater importance is the fact that the productivity of the matrices differs greatly in different genera.

In certain forms, e.g. Lacerta and Hemidactylus, the matrices functionate very intensively, the interval between two generations being very short. In such cases the tooth-families are rich in generations and frequently three generations in successive stages of development are found in addition to the functioning tooth. In other cases the interval between two generations is prolonged, the matrix has a limited power of production, and the generations of a tooth-family are few in number. A case in point is Calotes in which a search through the two jaws failed to find a single replacing tooth.

A knowledge of the tooth-genesis of reptiles is a necessity in order to understand the relationship between the teeth of the reptiles and those of the mammals, and further to understand the dimerous nature of the latter. The producing activity of the tooth matrices in different reptiles is such that the interval between two succeeding generations varies considerably. This interval, however, is sufficiently long in all reptiles for the last produced tooth to have reached a certain completion and independence before the matrix begins to produce the next generation. It is conceivable that the interval between two generations may be so shortened that the matrix produces a new generation

before the preceding generation has attained its independence; in short, a method of tooth formation where the interval between two generations is lacking. As a consequence, two generations will be intimately associated with one another during development, the younger generation instead of pushing out and replacing its predecessor fuses with it and a compound tooth, consisting in reality of two teeth, is the result. The conception may be extended to as many as ten tooth generations after the production of which the matrix becomes exhausted. In such a case a tooth homologous, not with a single reptilian tooth, but with a whole tooth-family is formed. Such teeth occur in mammals, e.g. in the extinct group of the Multituberculata and further in recent Proboscidea. In the latter every lamella of the tooth is homologous with a tooth or tooth-generation of the reptiles, the intervals between successive generations are lacking and generations are all so intimately associated with one another that the whole tooth-family forms but one large tooth. The morphological value of this extraordinary tooth-form, found in *Elephas Africanus*, upon which I am writing a special treatise, serves as a clue to the understanding of the tooth-form in the ordinary mammal.

The grinder of the elephant is homologous with a large number of reptilian tooth-generations, the potentiality of tooth production being very strongly developed in the matrix of this tooth. Such a tooth may be described as "polymeric." To understand the tooth-form normally occurring in mammals we may suppose that the productivity of the matrix is so limited, that after the production of two generations, the producing power is exhausted. Thus a tooth will be formed, homologous with two reptilian teeth, the whole tooth-family consisting of two generations only, coherent from their very commencement. Such a tooth may be described as "dimeric."

Although no interval occurs between the production of the two generations, nevertheless an older and a younger generation can be distinguished. The older generation forms the buccal part of the tooth, the younger the lingual, the two parts which I distinguish as the "Protomere" and the "Deuteromere" respectively. The Heterodonty of the mammalian dentition will be shown later to be due to the fact that the development of the deuteromere is very variable, and may even be entirely suppressed, as is the case for instance in the incisors and canines of some mammals.

I hope I have now proved to the satisfaction of the reader that the typical mammalian tooth is homologous with a reptilian tooth-family capable of producing a very limited number of generations.

An objection might be urged against my theory of multiple generations of a tooth-family being applied to the polymerous teeth of the Proboscidea and Multituberculata in that the successive generations are disposed not in a bucco-lingual direction as is the case in other mammals, but in an antero-posterior series. In such teeth the more anterior lamella represents the older generation, the hindmost lamella being the youngest. This apparently contradictory arrangement is to be explained, as I shall show in a forthcoming treatise

on tooth-genesis in the elephant, by the toothgerm undergoing a twist whereby the buccal side is displaced forwards and the lingual side backwards.

As, according to my view, the relationship between the dimerous teeth of the mammals and the reptilian teeth is such, that the former cannot be regarded as resulting from the coalescence of two independent entities of the latter, but rather as being due to the permanent association of two teeth which in the reptile would have succeeded one another and are derived from one and the same matrix, the process may be defined as one of "Concentration" in contra-distinction to "Concrescence." Hence I have entitled my view the "Concentration Theory."

The phenomena observed in the ontogeny of the mammalian tooth and fully described in the second essay, viz. the enamel-septum, the enamel-canal and the double connection of the enamel-organ with the general tooth-band, are now open to interpretation. The phenomena can be explained by reference to fig. 103, in which a complete mammalian enamel-organ is delineated. Attention has been already drawn to the fact that the enamel-septum and the double connection of the toothgerm with the dental lamina afford a twofold proof of the composite nature of the mammalian tooth. It is conceivable that each half of the enamel-organ is identical with the germ of a reptilian tooth, the mammalian toothgerm containing the anlage of two teeth. The formation of the enamel-canal (fig. 103, *e*), bordered by the internal and external dental lamina (fig. 103, *c* and *d*), is simply the manifestation of the special connections of the two anlage with the general dental lamina (fig. 103, *b*). The canal is not so much the essential feature as are its buccal (*d*) and lingual (*c*) walls, since the buccal wall (or external dental lamina) is the special connection of the buccal component, the lingual wall (or internal dental lamina) the special connection of the lingual component, of the toothgerm to the general dental lamina (*b*).

The composite nature of the toothgerm is manifested by the double centre of the pulp formation and by the enamel-septum with the enamel-navel (clearly shown in fig. 103), both indicating undeniably that the two components, lingual and buccal, take part in the construction of the germ. The fact that in some Marsupials bloodvessels enter into the enamel-septum (*vide* Essay II) may be considered as evidence that connective tissue primitively existed between and marked the independence of the two parts of the enamel-organ.

Although the composite nature of the layer of odontoblastic cells is scarcely demonstrable, yet it is conceivably so since Ahrens has discovered that this layer is discontinuous (*vide* Essay II).

The developmental history of the mammalian tooth clearly demonstrates its dimerous character and further it seems as if there is still some tendency for the two components of the tooth to become free and independent of one another and to re-acquire their respective individualities.

This tendency may be much stronger in some teeth than in others with a result that the composite nature of the tooth becomes manifest, its proto-

merous and deuteromerous components being more or less independent. Such variations occur chiefly in those teeth in which the deuteromere is normally greatly reduced, e.g. in the incisors and the canines. Although I am anticipating some future considerations, I may remark here that the so-called *Tuberculum dentis* of the incisors and canines is the deuteromerous component of these teeth and occasionally appears as a small free tooth. In such cases the two generations concerned with the building of the tooth are independent, and represent a condition normally existing in the reptiles. In other cases the deuteromere, though still connected with the protomere, attains a considerable degree of independence. Cases exemplifying this condition are represented in fig. 105, where two human medial upper incisors are shown. In (*a*) the deuteromere is so well developed that it appears as a free conical cusp arising from the lingual aspect of the crown. In (*b*) a supernumerary tooth is apparently adherent

Fig. 105.

Fig. 106.

to the lingual side of the normal incisor. A case in which the protomere and the deuteromere are completely independent is shown in fig. 106. This example is reproduced from Selenka, *Die Menschenaffen*, I. Lieferung, p. 141. It represents the frontal part of the upper jaw of a Gorilla with a so-called superfluous canine. Two grooves on the lingual aspect of the normal canine clearly differentiate the protomerous and the deuteromerous components of the tooth. These may be seen on the left canine. On the right side, two canines, a larger buccal and a smaller lingual, are present. The normal grooves on the lingual aspect of the larger buccal tooth are absent, clearly indicating that the two components of the normal tooth have developed independently. This case is quoted with intent, as a possibility of a superfluous canine is frequently denied and it disproves the statement that more than one canine never occurs in the functional dentition of the mammal. Supernumerary canines do occur, and are logically explained by my theory of the dimery of the mammalian tooth.

Further examples from the literature on the subject and from specimens in my own collections could be produced, but the two examples described will suffice as evidence of the dimery of the mammalian tooth.

Cases similar to these are frequently used by authors as proving the concrescence-theory. For instance, Kükenthal[1] defends the point of view as a result of his researches on the teeth of Cetaceae. I will discuss his researches

[1] *Denkschriften der medisch-naturh. Gesellsch. zu Jena*, III. Bnd

at some length, since in my opinion, they afford most excellent proof of my own theory. That the teeth of Cetaceae exhibit many phenomena in the direction of reduction, is a well known fact. The result of this reduction in the Odontoceti is an almost complete haplodont dentition. This reduction has progressed so far in the Mystacoceti that no functional teeth are developed at all.

In Kükenthal's opinion the teeth of Cetaceae are homologous with the milk-dentition of mammals. This assertion I do not intend to criticise, but the arguments he advances in favour of it prove, in my opinion, something entirely different.

Kükenthal describes a tooth with a prominent cusp on its lingual aspect as not infrequently occurring in Phocaena. Such a tooth is represented in fig. 107 (*a*) (Kükenthal, *l.c.* fig. 81). This cusp may even be provided with its own root, as represented in fig. 107 (*b*) (Kükenthal, *l.c.* fig. 82). Kükenthal interprets these cases as due to a growing together of a replacing tooth with a milk-tooth, and considers such teeth as evidence in favour of his assertion that the functionating teeth of the Cetaceae represent the milk-dentition, while the permanent teeth have undergone reduction. This interpretation can be easily refuted. Kükenthal's contention might have some weight if the process of tooth-change in the mammal were identical with that in the reptile and the milk-teeth and replacing teeth of the mammal stood in the same genetic relationship to one another as two tooth generations of the reptile. There is, however, as I shall show in my next essay, a fundamental difference between the process of tooth-change as it occurs in reptiles and in mammals. For this reason a concrescence of a milk-tooth with a permanent tooth is an impossibility.

Fig. 107.

Another striking argument against Kükenthal's interpretation can be adduced by comparing figs. 107 and 105. The remarkable resemblance between the two is obvious. Fig. 105 represents two permanent incisors with very strongly developed tubercula dentis. A precisely similar condition is represented in fig. 107. This identity in pattern, proves conclusively to my mind, that Kükenthal is in error in stating that the teeth of the Odontoceti are milk-teeth, and that the occasional supernumerary cusp on its lingual aspect represents a replacing tooth. The additional cusp in the Cetacean tooth must have the same significance as the additional cusp in the human tooth. In my opinion human incisors or Cetacean teeth provided with supernumerary cusps are in either case uncommonly strong evidence of the dimerous nature of the mammalian tooth and are due to unusually strong development of the deuteromere. If the fact that the teeth of Cetaceae are in a state of reduction be taken into consideration, the phylogeny of their tooth formation being regressive, this occasional dental modification is easily interpreted. As the dimerous mammalian tooth results from the concentration of two genera-

tions of a reptilian tooth family, the products of a twofold activity of the tooth-matrix persisting in intimate association, it is conceivable that in these anomalous cases the concentration is incomplete and a short interval occurs between the productions of protomere and deuteromere; as a result the latter acquires a certain degree of independence.

In the process of reduction to which the tooth of the Cetaceae has been subject, the second generation of the tooth family, the deuteromere, is lost first. The tooth of the Odontoceti consists in my opinion of a single generation only, viz. the protomere. This explains the resemblance between these teeth and those of the crocodile, to which they are, in fact, morphologically equivalent.

The fourth thesis does not present any further view, but formulates explicitly a fact necessarily sequential to the first and second theses.

According to the first thesis, the primitive element constituting the mammalian tooth is tricuspidate. The second thesis gives vent to the opinion that the mammalian tooth is the outcome of a union in a bucco-lingual direction of two reptilian teeth. Two conclusions may be drawn from these theses. In the first place, the primitive form of the mammalian tooth is sexicuspidate provided with three buccal and three lingual cusps, secondly every tooth of the set, however simple, is derived from this fundamental plan. The toothgerm of every tooth must therefore possess what Driesch calls the prospective potentiality of developing a sexi-cuspidate tooth. All toothgerms are equivalent in their morphogenic properties. Hence this thesis is designated the "Hypothesis of Equivalency."

The question as to whether or no all toothgerms are equivalent as concerns their prospective potentialities has no interest for the supporter of a concrescence theory, in which every cusp is considered as identical with a reptilian tooth. A corollary of the concrescence theory demands potential differences of a quantitative nature between the toothgerms, an idea incompatible with equivalency.

The question of equivalency must appeal to disciples of the differentiation theory, as set forth by Cope and Osborn. However, equivalency has never been propounded as a necessary qualification of the theory. On the contrary, its consideration exposes the weakness of the theory, at any rate when it was first promulgated, since the molars were regarded as fundamentally different from the other teeth. The tritubercular theory was applied at first to the molars only, a different method of development being tacitly assumed for the antemolars. Later a conformity in the patterns of the crowns of premolars and molars was conceived and considered to be the result of convergence. For instance, Osborn (*Evolution of mammalian molar teeth*, p. 195) states: "This premolar metamorphosis into the molar pattern is a very gradual process, and from the biological standpoint most interesting as illustrative of convergence, since forms exactly similar to the molars are finally attained from somewhat dissimilar beginnings."

The rest of the teeth, the incisors and canines, are left out in the cold and are not included within the scope of the Cope-Osborn theory. The "Premolar analogy" theory rests on a broader basis, as premolars and molars are considered together from a common point of view, but does not connote any idea of equivalency in tooth origin. Like the theory of Cope and Osborn it seeks to establish the homology of the cusps of the various teeth.

The concrescence theory, the tritubercular theory of Cope and Osborn, and the "premolar analogy" theory have one aim in common in that they all endeavour to explain how a numerical increase of dental cusps may be attained by some modification or other of a simpler form. As a consequence the discovery of factors determining the formation of new cusps to be superadded to those already in existence is a necessity. The fallacy of such a line of investigation is exposed in the latest (seventh) edition of Tomes' *Dental Anatomy* (pp. 366 *et seq.*).

Similar objections cannot be urged against my suggestion since the development of the various dental patterns is considered from an entirely opposite standpoint. The concrescence and the tritubercular theories are forced to explain the formation of new cusps by some evolutionary process whereby more complex forms are derived from less complex. If my views are accepted the various tooth-forms are to be explained in an entirely different manner. The problem resolves itself into determining the particular tooth-form in which all the potentialities possessed by the toothgerm are completely developed and which is, as a consequence, provided with the greatest possible number of cusps: further, should a tooth be provided with cusps smaller in number than the greatest possible, in determining which particular potentialities of the toothgerm are latent.

My theory therefore implies an involutionary principle applicable to all the teeth, and does not necessitate any artificial subdivision of the teeth into groups.

I lay no claim to absolute originality for the general idea underlying this principle. Ameghino introduced it, but applied it to the molars only. He was of the opinion that the primitive molar possessed six cusps, the number he found in Proteodidelphys, and that the molars of other mammals are derived from this form by a process of cusp reduction. Palaeontological observation led Ameghino to the same opinion as my own, but by an entirely different route. The molars of Proteodidelphys representing, as I opiniate, the fusion in a bucco-lingual direction of two reptilian tricuspidate teeth are the ideal realisations of my conclusions regarding the origin of mammalian teeth. Ameghino, on the other hand, is of the opinion that the sexicuspidate molar of Proteodidelphys resulted from a concrescence of six reptilian teeth. This opinion cannot be justified, since it implies a concrescence, partly at all events, in an antero-posterior direction. As I have mentioned already there is no particle of evidence to prove that a concrescence in such direction ever occurred in the course of evolution.

The teeth of the extinct Multituberculata have also served as a basis from which the tooth-forms of the recent mammals are to be derived. Taking into consideration that the Multituberculates are most primitive mammals, and that their molars possess a multiplicity of cusps, Forsyth Major supposes that the tritubercular molar is derived from a multitubercular by a process of cusp reduction.

Forsyth Major and Ameghino apply this principle of reduction to the molars, and are, in this restricted application, in agreement with the supporters of the tritubercular theory.

My theory differs essentially from the foregoing in that it applies to all the teeth comprising a dental set; all the teeth having had a similar developmental history are equivalent, the developmental potentialities of the front teeth as compared with the back teeth being to a great extent latent.

By summarising and combining all the different views regarding the form relations of the various teeth comprising a dental set, a result harmonising with my own particular view can be obtained. One group of investigators consider incisors, canines and premolars to be modifications of one original type, the molars being regarded as a group *sui generis*. A second group derive the premolars and molars from one common primitive type. Therefore some authorities include the premolars in one and the same group as the molars; others group them with the incisors and canines.

Opinion being at variance whether to put the line of demarcation between the canines and premolars, or between the premolars and molars, is fairly strong evidence that such demarcation is really non-existent and that all the teeth are modifications of one and the same fundamental type.

The form relationship between premolars and molars, was first advocated by Huxley. "In Centetes," writes this author, "it is easy to trace the successive changes by which the simple and primitive character of the mammalian cheek-tooth exhibited by the most anterior premolar passes into the complex structure of the crown of the posterior teeth[1]."

Topinard expresses a similar opinion: "Il y a donc," says the author, "unité d'origine des molaires supérieures et inférieures. Un type commun s'est différentié dans deux voies, qui se sont divisées et ont abouti l'une aux prémolaires, l'autre aux molaires[2]."

These views indicate a common ground plan for both premolars and molars. The opinion that the premolars and the front teeth may also have a common origin has also frequently found expression. For instance, Stehlin[3] expresses himself very definitely regarding the dentition of Suidae. The canine he believes is derived from a bicuspidate, biradical premolar tooth. As for the incisors, the author states "An den oberen Incisivi blickt die Prämolarenstructur noch

[1] *Collected Papers*, vol. IV, p. 450.

[2] "De l'Evolution des molaires et prémolaires chez les Primates et en particulier chez l'homme." *L'Anthropologie*, p. 670, 1892.

[3] "Über die Geschichte des Suidengebisses." *Abh. Schweiz. Palaeont. Gesellschaft*, vol. XXVI, 1899.

so deutlich durch, dasz sie sich am besten direct als modifizierte Prämolaren beschreiben lassen."

The upper incisors are found to resemble the premolars in shape in the Primates as well as in the Suidae. The lateral upper incisor of the genus Cebus, for instance, has a crown bicuspidate to such degree that the tooth may be easily mistaken for a premolar. The upper incisor of Siamanga syndactylus has a posterior cusp nearly as large as the anterior.

According to Zucherkandl, the canines and premolars are modifications of one and the same original form[1].

Finally, to quote d'Eternod[2] who comes to the conclusion that: "Toutes les dents humaines sont des bicuspides modifiées."

Summarising the opinions of these several investigators the idea of a uniformity of plan underlying the conformation of all the teeth seems definitely to exist. This conclusion is arrived at as a result of comparing the crown-patterns of the adult teeth. I arrive at identically the same conclusion as a consequence of the manner in which, in my opinion, the mammalian tooth takes origin, viz. by a concentration of the germs of two tricuspidate reptilian teeth. It was only *a posteriori* that I examined in detail the teeth of Primates, in order to learn how far facts were in accordance with this principle. The results of this investigation have already been published in detail[3].

Some further points which can be elucidated by my theory may now be considered. According to my theory mammalian teeth are identical with two generations of a reptilian tooth-family together forming a morphological unit, no interval occurring between two successive producing activities of the tooth-matrix. Of the two generations, the first or protomere represented by the buccal row of cusps, is the older; the deuteromere represented by the lingual row of cusps, is the younger.

When all the potentialities of a toothgerm are not developed, it is naturally the deuteromere which is incomplete or entirely absent. Such is the case with the incisors and canines. The deuteromere is usually completely suppressed in the incisors of the lower jaw, in the upper jaw, on the other hand, it is present and is represented by the so-called *Tuberculum dentis*. Primitive triconodonty is very often clearly indicated in the protomere and may be occasionally seen in the deuteromere of the incisors.

The canines of the Primates vary considerably as regards the degree of development of their fundamental morphological characters. In the human canines as well as in those of other Primates in which these teeth are not well developed, the deuteromere is completely suppressed, any indication of its presence on the lingual side of the crown being absent. In the well-developed canines of Gorilla, Cynocephalidae and Cebidae on the other hand, two longitudinal grooves on the lingual side of the crown are the lines of demarcation

[1] *Anatomie der Mundhöhle.* Wien, 1891, p. 44.
[2] *Verhandl. Anat. Gesellsch.* Leipzig, 1911.
[3] *Odontologische Studien* II. *Die Morphogenese der Primatenzähne.* Jena, 1913.

between the larger protomerous and the smaller deuteromerous elements of the tooth. The protomere of the less specialised human canine sometimes exhibits its primitive triconodonty in a very beautiful manner.

The marked reduction of the deuteromere is a common characteristic of incisors and canines, and the potentiality of development of this part of the tooth remains more or less latent in the germ, but may become active, as has been previously shown by some very instructive cases.

The deuteromere is usually more strongly developed in the premolars, although its degree of development varies considerably. It is as a rule relatively less well developed in the first premolar, but it may be so large in the last premolar that protomere and deuteromere are equal in size. Accessory cusps are also more evident in the premolars than in the incisors and canines.

A feature, enabling us to understand the pattern of the molars, can be observed in the hindmost premolar of Primates. In the early part of this essay I suggested a crown-formula for the teeth, and may remind the reader that the principal cusp of the protomere is indicated by the symbol *P*, the accessory cusps by 1 and 2; the main cusp of the deuteromere by the symbol *D*, and the accessory cusps by 3 and 4. A premolar in which the two main cusps alone are developed is indicated by the crown formula;

$$\frac{P}{D}.$$

As regards the extents of their several developments, the premolars of the Primates usually present a progressive series from before backwards. The hindmost may be so strongly developed that the principal cusp of the protomere is subdivided into anterior and posterior cusps. This is indicated in the crown-formula by writing two symbols: *Pa* and *Pp* in place of *P*. Such a subdivision is found, for instance, in the hindmost premolar of the lower jaw of Galago, Hemigalago and Avahis, and in the upper jaw of Galago and Hemigalago. The hindmost premolar of these genera exhibits a pattern similar in all respects to that of the first molar, and is judged to be a premolar, not from the conformation of its crown, but from its position in the series. A similar appearance, but in a somewhat less degree, is seen in the second lower premolar of Inuus, Cynocephalus and even Gorilla and Chimpanzee, and in the third premolar of Hapale. The subdivision of *P* into *Pa* and *Pp* is associated with a very strongly developed *D*.

In tracing the developmental features of the teeth constituting a dental series from before backwards, it is now obvious that the essential feature is the progressive increase of the deuteromere culminating in the molars. As the principal cusp of the deuteromere becomes strongly developed, the main cusp of the protomere lengthens and when associated with a more strongly developed deuteromere may be subdivided into two daughter-cusps.

In some cases the deuteromere of the premolars of Primates may be provided with a strongly developed posterior accessory cusp, to be indicated by the symbol 4. As a rule this cusp attains such a degree of development

in the molars as to equal in size the main cusp of the deuteromere. Consequently the general crown-formula of the Primate-molar is as follows:

$$\frac{Pa\ Pp}{D\ 4}.$$

In addition one or more of the three remaining accessory cusps (1, 2 or 3) may be present.

This brief account will make clear what I mean by the equivalency of all the teeth. The germs of all teeth possess the potentiality of developing a sexicuspidate tooth. This potentiality is a consequence of the modus in which the mammalian tooth was evolved. Two possibilities may eventuate, either all potentialities may activate or one or more may be latent. As a rule the whole deuteromere is latent in the incisors and canines or when present is a mere vestige. In general the development of all the accessory cusps is much more variable than that of the two main cusps.

I consider all the teeth as having had origin from an equivalent matrix. From this standpoint the incisors and canines as compared with the premolars and molars are not to be considered as teeth which have undergone reduction. No question of a real reduction is involved, since the cusp-forming potentialities in the germs of these teeth are, in contradistinction to the molars, incompletely developed. Hence my definition in Thesis 4: complication is coincident with completeness.

Finally, two features, viz. the *Tuberculum impar* or cusp of Carabelli and the Cingulum both of which have some bearing on my theory of the origin of the mammalian tooth will be considered. The *Tuberculum impar*, to which comparatively little attention is paid by English writers, will be considered first.

This tubercle has a very important bearing on the problem of the homology of the cusps characterising the Primate dentition. I have already alluded to the fact that the main cusp of the protomere *P*, usually simple in the premolars, is subdivided in the molars into two daughter-cusps, distinguished as *Pa* and *Pp*. Homologising these cusps is of such importance that further evidence must be adduced in support of this assertion. That two cusps on one tooth are together homologous with a single cusp on another is a somewhat bold and novel statement. However, such a view helps to solve the difficulty of homologising the cusps of the premolars with those of the molars.

I was led to this opinion by comparing the pattern of the hindmost premolar in Primates with that of the first molar. The factor causing the cusp *P* to be subdivided into the cusps *Pa* and *Pp* is the very strong development of the adjacent cusp *D*. Evidence supporting this supposition can be drawn from direct morphological observations made on the hindmost premolars of some Primates, and the *Tuberculum impar*, which is not infrequently met with in man, is a further convincing proof. I have had the opportunity of examining this supernumerary cusp in some thousands of molars.

The genetic and morphological significance of the *Tuberculum impar* must first be proved and I shall show, subsequently, that the excessive development of this cusp, situated on the lingual side of *D*, is a factor causing the latter to subdivide into two daughter cusps, *Da* and *Dp*, in precisely the same way as the excessive development of *D* compels the main cusp of the protomere *P* to subdivide into the daughter cusps *Pa* and *Pp*.

The genetic importance of the *Tuberculum impar* may be explained as follows. The mammalian tooth is a dimerous organ homologous with two generations of a reptilian tooth-family, which as the protomere and the deuteromere, both take part in the building of the tooth. Normally the mammalian tooth-matrix is endowed with the potentiality for producing two generations only, which are intimately associated with one another as a result of concentration. Primitively a tooth-matrix possesses the potentiality of producing more than two generations. Should the matrix be capable of producing a third generation the result would appear on the lingual side of the principal cusp of the deuteromere, and a little eminence or even a cusp in this situation may be considered as the indication of the principal cusp of the third generation. In such case, the tooth is not a dimerous organ but is in reality trimerous and the manifestation of a third generation can therefore be distinguished as the "Tritomere" its cusp being indicated by the symbol *T*. The cusp *T* is commonly denoted the *Tuberculum impar* or the cusp of Carabelli. This cusp is simply a manifestation of a third generation of the mammalian tooth-family, in persistent association with the second generation in precisely the same manner as the latter is associated with the first generation. The crown-formula of a molar provided with a *Tuberculum impar* is therefore

$$\frac{\frac{Pa\ Pp}{D\ 4}}{T}.$$

The *Tuberculum impar* has been found associated at one time or another with every tooth of the upper jaw in man, but not so frequently with some teeth as with others. I will not present the results of my investigations upon the frequency of this cusp, but the following figures prove that I have had ample opportunity of studying it. In 300 *m* 2, the cusp was present 54 times; in 2325 M_1, 407 times; in 2072 M_2, 144 times. I intend to publish shortly a detailed account of an investigation on this cusp found in Primates other than man. Certain information concerning and some diagrams illustrating this cusp may be found in a treatise already published[1]. From the figures given above it is apparent that this cusp is not rare in man, where it is found more frequently in M_1 than M_2.

When the cusp *T* is well developed, it has a marked influence on the cusp *D*. I have been able to trace the gradual effect of this influence. The cusp *D* first widens then a shallow furrow is formed incompletely subdividing the cusp.

[1] "Das Carabellische Höckerchen," *Schweiz. Vierteljahrschrift für Zahnheilkunde*, vol. XXV, 1915.

Finally, when *T* is very strongly developed the furrow becomes so deep that the cusp is completely split into two daughter-cusps, which may be distinguished as *Da* and *Dp*. The crown-formula of such a molar is

$$\frac{\frac{Pa\ Pp}{Da\ Dp}\ 4}{T}.$$

As a matter of detail the crown of such a molar is somewhat irregular.

I must emphasise the importance of the foregoing description of the behaviour of the cusp *D* as it makes the general crown pattern of the molar teeth intelligible. The cusp *T* must be considered as the main cusp of a third generation, participating in the building up of a tooth. It is adjacent to cusp *D*. In those cases, in which this cusp *T* is strongly developed, the cusp *D* is sub-divided into two daughter-cusps. This process elucidates the homology of the premolar and the molar patterns. In the premolar the cusp *D*, adjacent to the cusp *P* is moderately developed; in molars, on the other hand, it is as a rule strongly developed and as a consequence the cusp *P* is sub-divided into two daughter-cusps.

In my opinion the pattern of the molar teeth does not result entirely from concentration as I use the term, but is also partly due to differentiation.

I cannot close this essay without briefly discussing the theory of the origin of the premolar pattern as formulated by Marett Tims[1].

He thinks the cingulum is of great importance in the genesis of the premolars, the molars being considered as formed by a concrescence of two premolars. With the latter opinion I cannot agree, as there is no evidence of a concrescence of teeth in an antero-posterior direction ever having taken place as a normal evolutionary process, but I am more inclined to agree with him respecting the importance of the cingulum.

Marett Tims makes a great point of the so-called "internal cingulum" possessing the faculty of forming cusps, e.g. the protoconus of the premolars. Translated into my own nomenclature the "Protoconus" is cusp *D*, the principal cusp of the deuteromere, and I fully agree with him that a genetic relationship exists between the internal cingulum and this cusp *D*. I consider the cingulum to be the manifestation of the deuteromere. When very slightly developed, the latter does not exist as a cusp, but as a small inconspicuous eminence, as is the case, for instance, in the deuteromere of the upper incisors. Marett Tims' observation that all intermediate conditions between a simple cingulum and a well-developed cusp may be met with is obviously true.

The same applies to the tritomere. This may be slightly developed as a low ridge, and also exhibits progressive increase, ultimately attaining the dignity of a true cusp.

Odontological problems of vast importance concerning the relationship between mammalian and reptilian teeth and the causes of Heterodonty have

[1] "The Evolution of the Teeth in Mammalia," *Journ. of Anat. and Phys.* vol. XXVII, 1903.

been discussed in this essay. My conceptions run counter to current opinion and will, doubtlessly, be subjected to criticism. I would plead, however, that considered judgment be suspended until the appearance of my fifth essay, in which the second great odontological problem, viz. the relationship between the diphyodonty of mammals and the polyphyodonty of reptiles will be discussed. I hope to prove that the processes of tooth-change in reptiles and mammals are two entirely different phenomena and that the reason for the appearance of the dimerous tooth in the mammal is to be sought for in the profound change which has affected the primitive features of tooth replacement.

As the two fundamental odontological problems are closely inter-related and both come within the compass of my general conceptions, the complete evidence upon which my theory stands or falls has yet to be unfolded.

CORRELATION BETWEEN HABIT AND THE ARCHITECTURE OF THE MAMMALIAN FEMUR

By G. de M. RUDOLF, M.R.C.S. (Eng.), L.R.C.P. (Lond.), D.P.H.

King's College.

The object of the investigations undertaken is the study of the architecture of the upper end of the femur and the relationship which this bears to the habits of its owner.

With this object in view, coronal sections were made through the upper ends of femora of various animals.

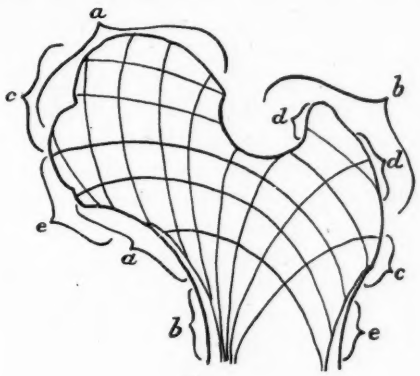


Fig. 1.

As a standard of comparison the human femur will be taken as the type. Koch (5) classifies the lamellae exhibited by a coronal section of the upper end of this bone in five groups (fig. 1). For convenience of description these groups are marked *a*, *b*, *c*, *d*, *e*. The characteristics of these groups are as follows:

(*a*) Principal compressive group. The lamellae are closely packed. They are the thickest found in the upper end of the femur and are mainly prolonged from the inner wall of the shaft. The lamellae exhibit no change as they cross the epiphysial lines.

(*b*) Secondary compressive group. Trabeculae thin. Intervening spaces wide.

(*c*) Principal tensile group. Lamellae thinner and more widely spaced than those of group (*a*).

(*d*) Secondary tensile group. Lamellae very thin and poorly defined.

(*e*) Group of tensile lamellae situated below, and parallel to group (*c*).

According to Wolff's law the arrangement of the lamellae may be regarded as a response to the normal stresses and strains to which the part of the bone

is subject. Consequently, this arrangement will depend upon the use made of the bone by its owner, and thus is an index of the habits of the creature. Murk Jansen (4), however, believes, contrary to Wolff's law, that lamellae are never laid down as the result of tension, but only of pressure. He also believes that "functional pressure" is not the only factor determining bone formation, but that there are other factors which make themselves felt in the formation of bone.

The mammalian femora providing the material for this thesis can, for descriptive purposes, be divided into three main classes:

I. Compact class. The femora in this class contain a large number of closely packed lamellae.

II. Loose class. The femora contain a small quantity of widely spaced lamellae.

III. A class characterised by the appearance of two new sets of lamellae, *f* and *g*. These converge towards one another in the substance of the great trochanter, crossing each other at angles varying in different animals.

Each class may be further divided into two sub-classes, 1 and 2. In sub-class 2 of class I the lamellae are more widely spaced and less numerous than in sub-class 1. In sub-class 1 of class II the lamellae are closer and more numerous than in sub-class 2. In class III, sub-class 1 consists of aquatic mammals, sub-class 2 of creatures with leaping habits.

The femora examined, and their classification, are as follows:

Class I. Compact class.
- Sub-class 1. (i) Aard-Vark (*Orycteropus*).
  - (ii) Brown Bear (*Ursus arctos*, var. *isabellina*).
  - (iii) Great Anteater (*Myrmecophaga jubata*).
  - (iv) Domesticated Horse (*Equus caballus*).
    - (*a*) Cart-horse.
    - (*b*) Carriage-horse.
    - (*c*) Pony.
  - (v) Man (*Homo sapiens*).
  - (vi) Domesticated Pig (*Sus*).
- Sub-class 2. (i) Domesticated Sheep (*Ovis aries*).

Class II. Loose class.
- Sub-class 1. (i) Domesticated Dog (*Canis familiaris*).
  - (ii) Three-toed Sloth (*Bradypus tridactylus*).
- Sub-class 2. (i) Domesticated Cat (*Felis domesticus*).
  - (ii) Diademed Sifaka (*Propithecus diadema*).
  - (iii) Stoat (*Mustela erminea*).
  - (iv) Brown Rat (*Mus decumanus*).

Class III.
- Sub-class 1. (i) European Beaver (*Castor fiber*).
  - (ii) Monk-Seal (*Monachus albiventer*).
  - (iii) Northern Sea-Bear (*Otaria ursina*).
- Sub-class 2. (i) Great Grey Kangaroo (*Macropus giganteus*).

The individual bones will now be considered.

Aard-Vark. This animal, being very heavy for its size, needs a strong femur. The lamellae are very closely packed and numerous. The aard-vark is a creature that lives on hard ground and is an expert at rapid digging, being able to dig a hole sufficiently large to bury its entire body in a few minutes. The hole is dug by means of the fore-feet, the clods of earth being passed backwards between the hind-limbs (8). Thus the animal must support itself for short spaces of time upon its hind-limbs alone. These considerations, combined with the knowledge that the femora of the creature must, when the animal is trotting, be continually receiving sudden shocks on coming into contact with the hard ground, would lead to the assumption that the lamellae would be not only numerous and closely packed, but also arranged in definite and well-marked groups. The femur, however, only exhibits two main groups of lamellae, namely *a* and *c*, and these are not so distinct as is the case in femora of other animals. Possibly this is due to the relationship of the aard-

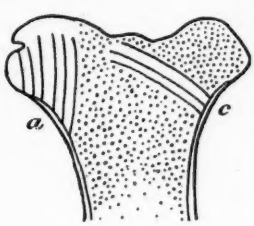


Fig. 2. Aard-Vark.

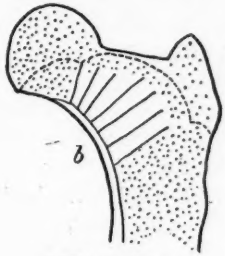


Fig. 3. Bear.

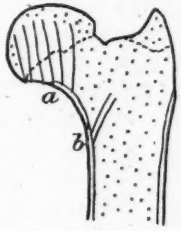


Fig. 4. Anteater.

vark to the anteaters of South America. Lydekker states that it is "urged that during the connection of America with Africa the latter country received from South America the ancestors of its pangolins and aard-varks (10)."

Brown Bear. The species examined is another heavy animal and inhabits wooded hilly districts in the Himalayas. Its food consists of insects, fruit, etc. (6). In order to reach the vegetarian part of its diet, the bear must ascend the trees. As the animal commences to climb, it must first raise itself up on its hind-limbs and place its fore-paws up the trunk of the tree. In this position the hind-limbs must support nearly the whole weight of the body. To enable the femora to withstand this enormous strain the lamellae are very closely packed. Group *b* is particularly well-marked. Possibly the reason for this may be found in the manner in which the animal walks. A bear does not move its hind-foot forwards in a straight line, but swings the foot forwards in the arc of a circle, convex outwards. Towards the end of this swinging movement the foot is moving forwards and inwards. Consequently the inner side of the foot bears the brunt of the sudden impact with the ground, and the inner part of the limb must be proportionately strong in order to withstand the immense strain put upon it.

Anteater. The femur of this animal has only one well-marked group of lamellae, group *a*, although group *b* is distinguishable. The anteater lives in wet, swampy districts(11), and, owing to the yielding nature of the ground on which the animal walks, the femur is not often subject to loads applied suddenly. The immediate effect of stresses applied suddenly is approximately double that of the same force applied gradually(5). From this it follows that the groups of lamellae in the femur of the anteater need not be so well-marked as would be necessary if the animal lived upon hard ground. The lamellae are fairly closely packed, though not to the extent found in the femur of the aardvark. This can be explained not only by the consistency of the surface upon which the animal walks, but also by the fact that as the anteater is not a burrower, it does not support itself upon its hind-limbs alone. The only digging performed by the animal is confined to opening the nests of termites(11), and this can be done with one fore-paw alone.

Horse. The femur of the domesticated horse must be exceedingly strong, for not only is this animal heavy, but also it lives on hard roads, over which certain types, e.g. the carriage-horse, move rapidly. The speed at which an animal travels may make a great difference in the lamellae of the femur, for the load borne by the femur during running is much greater than that borne during walking. In the case of Man, the load is 1·6 of the body weight during running, and only ·8 of the same weight during walking(5). This is another form of the statement already made that stresses applied suddenly are double those produced gradually. The load in walking is so cushioned by ligaments, etc., that it equals a load applied gradually, whereas in running the ligaments are not sufficient to break the force of the load, with the consequence that the stresses are applied suddenly.

(*a*) Cart-horse. The femur of this animal is very massive compared with that of the pony. There is a large amount of closely packed lamellae. Groups *a* and *e* are well-marked, the former being the more prominent. The upper surface of the great trochanter is at a level higher than that of the head of the bone. This is, perhaps, connected with the manner in which the horse rises from the ground. The animal first sits on its haunches in the same way as a cat, and then springs suddenly on to its hind-feet, not rising in the more leisurely fashion of the carnivore. This movement of springing on to the hind-feet is similar to that of jumping, and, as will be shown later, jumping habits are associated with a high great trochanter. The reason for this association in all probability lies in the circumstance that an extended great trochanter increases the leverage about the axis of the neck of the femur and so enables a greater movement to be performed without too great an expenditure of energy. There is a certain amount of flattening of the head of this femur. This is perhaps partly due to the pressure exerted by the head upon the acetabulum when the horse rises from the sitting position.

(*b*) Carriage-horse. As would be expected, the lamellae are not so closely packed as are those of the heavier cart-horse. Group *a* is very prominent, as

is also group *c*. There is a large quantity of cancellous tissue, extending some distance down the shaft.

(*c*) Pony. The lamellae of group *a* are well-marked, although those of group *e* are not very prominent. The walls of the bone are relatively thicker than in either the cart-horse or the carriage-horse. Apparently, in the smaller, active animals strength is obtained by an increase in the amount of compact bone, the cancellous tissue being relatively scanty.

The femora of these three types of the same species demonstrate two facts, (*a*) that the compactness of the lamellae varies directly with the intensity of the stresses and strains to which the femora is subject, and (*b*) that the height of the great trochanter bears a direct relationship to the agility of the animal. That this is the case is shown by the observations that the lamellae are most

Fig. 5. Cart-horse.

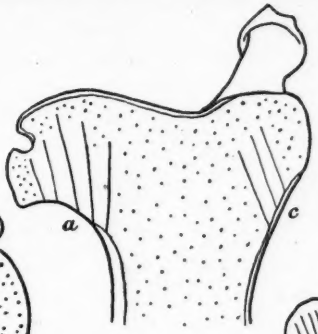


Fig. 6. Carriage-horse.

Fig. 7. Pony.

closely packed in the cart-horse and least so in the pony, and that the great trochanter of the cart-horse is relatively shorter than that of the pony. The carriage-horse occupies an intermediate position both as regards the compactness of the cancellous tissue and the height of the great trochanter.

Pig. The femur of this animal contains a moderate quantity of cancellous tissue. The lamellae are very closely packed as might be expected when the weight of the animal is considered. The walls of the bone are thick. The lamellae of group *a* are very well-marked. Group *e* is the only other group at all prominent. The absence of many well-marked groups agrees with the habits of the pig, for this animal lives upon soft ground and is rather inactive. The prominence of group *a* is probably caused by the relatively huge weight of the animal, whereas the prominence of group *e* is no doubt due to the position of the bone when the animal is standing. As in Man, the femur is obliquely inclined, the distal end being nearer the middle line than the proximal.

Consequently, the greater part of the weight supported by the femur will be transmitted along the lateral part of the bone. On this account there is more cancellous tissue laterally than medially, and group *e*, along which a large part of the weight is transmitted, is prominently marked.

Sheep. The cancellous tissue is more open in this bone than in any of the preceding members of the class. The amount is relatively less than in the femur of the pig. Group *a* can be seen, while groups *b* and *e* are barely recognisable. The upper surface of the head is flattened, and the summit of the great trochanter is at a higher level than that of the head. This latter characteristic is probably due to the habits of the sheep, for, although the modern domesticated sheep is not as a rule very active, the wild sheep and the domesticated sheep allowed to run wild are very agile animals. The flattening of the head of the bone is possibly caused by the great weight of the creature at certain periods of its life, combined with the small amount of circumduction possible in the movements of the hind-limbs. Neither the high great trochanter

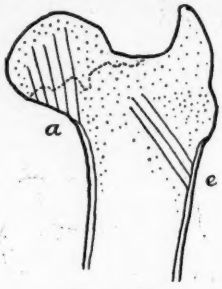


Fig. 8. Pig.

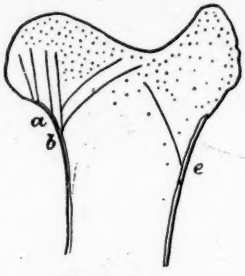


Fig. 9. Sheep.

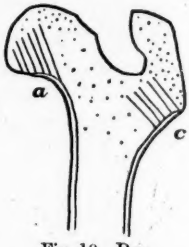


Fig. 10. Dog.

nor the flattening of the head can be due, as in the case of the horse, to the manner in which the sheep rises from the ground, for the latter raises its hind-quarters first, and then gradually straightens out its fore-limbs. Thus there is no great pressure exerted upon the head of the bone in this movement, nor is there any need for a great deal of leverage.

Dog. This animal is a representative of class II in which very few lamellae are present. In the femur of the dog, that of a fox-terrier being the bone described, the lamellae are fairly widely spaced. Groups *a* and *c* are well-marked, although neither is very prominent. The wall of the bone is thick. The top of the great trochanter is level with the upper surface of the head of the bone. This might suggest that, although the dog is able to jump, it is not primarily built for that purpose.

Sloth. The lamellae of this femur are less closely packed than are those of the dog. The compact bone on the superior aspect of the head is thin, and the neck forms a very wide angle with the shaft. The sloth passes most of its life hanging by its feet from boughs in an inverted position. Thus the neck and the shaft of the femur tend to be pulled into one straight line, for the weight

of the animal will be supported by the leg and thigh. Flower states that the neck of the femur of this animal is nearer the axis of the shaft of the bone than in most other animals (1). The habitual attitude of the animal involving no pressure upon the proximal end of the femur, the compact bone investing the head is thin. There are three well-marked groups of lamellae, *a*, *c* and *d*. As the sloth hangs from the bough there is a tendency for the neck of the femur to be pulled into the line of the shaft, and also a component pressure force tending to press the head of the bone against the acetabulum. Group *c*, situated in the head of the bone, is well-marked and obviously resists this flattening tendency. Group *a* is probably well-marked in order to support *c* to prevent the latter from "buckling." The slight prominence of group *d* may be accounted for by the fact that the muscles attached to the great trochanter must, to some extent, support the weight of the body from the bough, and the group referred to may resist a tension strain.

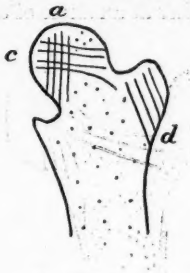


Fig. 11. Sloth.

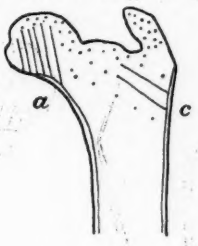


Fig. 12. Cat.

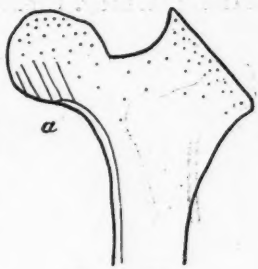


Fig. 13. Sifaka.

Cat. The amount of cancellous tissue is even less in this femur than in that of the sloth. The only group of lamellae readily distinguished is group *a*, although group *c* can just be recognised. As the cat is an active animal it might be expected that the various groups would be well marked. The animal is adapted, however, not only for agile movements, but also for stealthy and silent tread. The feet are therefore well-padded and the ligaments allow a certain amount of "play." The full force of a fall is not received by the femur, the ligaments and pads acting as disseminating cushions. The strength of the bone mainly depends on the compact tissue, the walls being comparatively thick.

Sifaka. The sifaka, or propitheque, is one of the lemurs. The cancellous tissue in this femur is very slight indeed. The sifaka is an exceedingly active animal. It spends most of its life in the trees, rarely coming to the ground; there is therefore a reduction in the amount of the cancellous tissue. When on the ground the sifaka progresses by means of long leaps of about ten yards, not using the fore-limbs at all (3). The requisite strength of the femur is obtained by the walls of the bone being relatively thick. The great trochanter rises slightly above the level of the head of the bone. This is no doubt associated with the leaping habits of the animal.

Stoat. This is another active animal whose light weight facilitates its rapid movements. Little cancellous tissue is present. Group *a* is fairly distinct, enabling the femur to resist the sudden shocks to which it is subject.

Rat. This femur contains relatively less cancellous tissue than does that of the stoat. This is presumably associated with the agility of the rat, for this animal can not only run rapidly, but also climb and swim. As would be expected from the habits of this creature, group *a* is fairly prominent.

Beaver. The beaver is included in class III. In this class two additional groups of lamellae (*f* and *g*) are found. The lamellae in the femur of the beaver are very closely packed. The reason for this is not far to seek, the animal being very heavy, and the weight mainly disposed in the hind-quarters. A beaver may weigh as much as 60 lbs. while the length of the body is only 30 ins. Swimming being almost entirely performed by the hind-limbs (7), the muscles of these extremities are very large, accounting for the great weight of the caudal end of the body. Groups *f* and *g* meet one another at an angle of about

Fig. 14. Stoat.

Fig. 15. Rat.

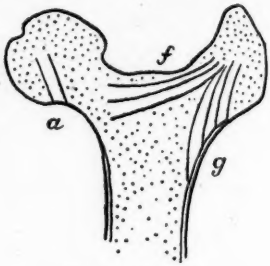


Fig. 16. Beaver.

45°. The great trochanter rises slightly above the superior aspect of the head of the bone.

Monk-Seal. As in the beaver, there is a large amount of cancellous tissue, although the lamellae are not so closely packed. As the seal does not support itself upon its hind-limbs at all, but only uses them as a rudder, a very strong femur is not a necessity. Consequently, the cancellous tissue is not very closely packed. Groups *f* and *g* converge towards one another at an angle of about 90°. (In fig. 17 this angle is represented as being greater than it actually is.) Groups *a* and *b* can just be recognised. The great trochanter rises to about the level of the upper surface of the head of the bone.

Northern Sea-Bear. This creature is one of the eared seals. The femur exhibits a large amount of cancellous tissue. The walls are thick, more especially the lateral one. This is explained by the oblique disposition of the shaft of the bone, more marked than in the case of the sheep. The bone must of necessity be stronger than that of the monk-seal, for the sea-bear supports its body on its hind-limbs, as well as using them as a rudder. The great trochanter does not reach to the level of the superior surface of the head.

Groups *f* and *g* meet one another at an angle which is slightly greater than a right angle.

Kangaroo. The great trochanter in this animal is exceedingly prominent, being exaggerated by the flattening of the superior surface of the head. Group *f* converges towards group *g* at an angle of about 70°. The flattening of the head of the bone is probably partly due to the jumping habits of the animal combined with its great weight. Towards the end of a leap, when the hind-limbs reach the ground, the body is carried forwards for an instant by its own momentum until it is stopped, partially at any rate, by the impact of the acetabulum on the head of the femur. The Great Grey Kangaroo weighs about 14 stone, while the length of the head and body is only 5 ft. 3 ins.(9), consequently the impact between the acetabulum and the head of the bone must be very great. This probably accounts for the flattening of the head. Group *a* is fairly well developed in order to resist this tendency to flattening. The upper surface

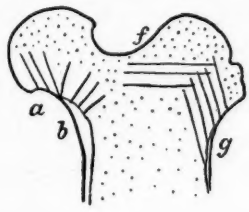


Fig. 17. Monk-Seal.

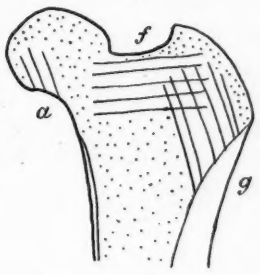


Fig. 18. Sea-Bear.

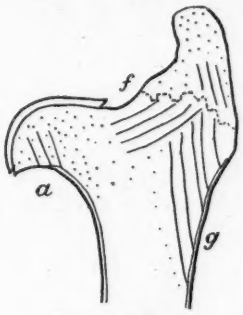


Fig. 19. Kangaroo.

of the head of the bone is provided with a thick cap of compact bone. This is presumably protective and caused by hypertrophy of the compact bone due to the severe intermittent pressures to which this part of the bone is subject.

SUMMARY

The facts given in this paper would suggest that there is a definite correlation between the habits of the animal and the structure of the upper end of the femur.

The characteristics of the upper end of the femur in association with the habits can be summarised as follows:

(*a*) If the upper limit of the great trochanter is above the level of the upper surface of the head of the femur, the animal is able to jump or leap, or to perform similar movements, such as rising rapidly from the sitting posture, as exemplified by the horse. The use of the hind-limbs for swimming is also apparently associated with a high great trochanter.

(*b*) Flattening of the superior surface of the head of the bone appears to be associated with the receiving of relatively great stresses on this surface.

(*c*) The thickness of the walls of the femur depends upon at least two, and perhaps three, factors, namely, (1) the amount of cancellous tissue present, this varying inversely as the thickness of the walls; (2) the intensity of the stresses and strains acting on, and through, the femur; and possibly (3) the histological structure of the bone, for Foote has shown that the histology of the femur varies with the race and species of the animal (2).

(*d*) The quantity of cancellous tissue varies directly with the relative weight of the animal. Therefore the lighter animals tend to have little cancellous tissue and thick walls. The quantity of cancellous tissue may be associated with the histological character of the bone.

(*e*) Groups of lamellae are well-marked if the stresses and strains borne by the groups are large.

(*f*) The two groups of lamellae *f* and *g* are not found in the human femur, but when present in a femur of one of the lower animals would appear to indicate the use of the hind-limb for the purpose of swimming, leaping or similar movements.

In conclusion, I feel I must thank most sincerely all who have assisted in the preparation of this article. In particular I must thank Professor E. Barclay-Smith and Dr R. J. Gladstone of King's College, London for their invaluable advice and help. I also wish to thank all those who so kindly supplied me with material, especially Mr W. P. Pycraft and Dr A. Smith-Woodward of the British Museum (Natural History), also Professor Shave of the Royal College of Veterinary Surgeons, Sir Charlton Briscoe, M.D., of King's College Hospital, and Dr G. W. Robinson.

REFERENCES

(1) Flower, W. H. (1885). *Osteology of the Mammalia*, p. 336.
(2) Foote (1916). "A contribution to the comparative histology of the femur." *Smithsonian Contributions to Knowledge*, 35, No. 3.
(3) Grandidier (1894). Quoted in Lydekker, *Royal Natural History*, 1, p. 207.
(4) Jansen, M. (1920). *On Boneformation*, p. 107.
(5) Koch. *Amer. Journ. Anat.* 21, No. 2.
(6) Lydekker, R. (1894). *Royal Natural History*, 2, p. 12.
(7) —— *Ibid.* 3, pp. 96–100.
(8) —— *Ibid.* 3, p. 234.
(9) —— *Ibid.* 3, p. 241.
(10) —— *Encyclopaedia Britannica*, Edit. 10, 33, p. 941.
(11) Mivart, St G. 1894). *Types of Animal Life*, p. 255.

ON CERTAIN NORMAL IRREGULARITIES IN THE VERTEBRAL COLUMN IN ITS LOWER DORSAL AREA

By EDGAR F. CYRIAX, M.D. (Edin.),

London.

When a subject is lying face downwards, palpation of the spinous processes of the lower dorsal vertebrae will frequently reveal irregularities; in some cases they are even obvious to mere inspection. These irregularities, though normal in the site mentioned, would be indicative of disease or trauma if encountered elsewhere in the vertebral column; due appreciation of these facts is therefore of importance.

These irregularities seem up to the present to have escaped detection; I have never seen them depicted in diagrams or described in the text in anatomy books. They are as follows:

(1) The spinous process of D 10 is slightly shorter than those of the bones immediately above and below it; differences of $\frac{1}{8}$ inch are quite common. Thus the spinous process will apparently be depressed and will lie in front of the line joining the spinous processes of D 9 and D 11; a forward displacement of D 10 will thus be simulated. In rarer cases the above will be found in D 11 instead of D 10.

(2) The spinous process of D 10 is situated at a slightly higher level than normal as regards the body of its vertebra. Thus the space between it and the spinous process immediately above it becomes considerably reduced. A tilt of the vertebra or possibly a fracture of the spinous process with displacement upwards will thus be simulated. In rarer cases the above will be found in D 9 or D 11. This appearance of a displacement is often accentuated by the fact that the interspinous ligament uniting the spinous processes of the irregular vertebra to that of the bone immediately below it is somewhat curved (i.e. concave when viewed from behind) instead of being practically a straight line, thus simulating the ligamentous atrophy which is so common an accompaniment of vertebral displacement[1]. This ligamentous irregularity, though generally confined to the one interspinous space mentioned, may also be found in one or more of the spaces below it as far as the sacrum.

One or other of the above irregularities is found, roughly speaking, in about 20 per cent. of all subjects. The close proximity of two dorsal spinous

[1] Cyriax, *Journ. de chir.* xv. 472, 1919.

processes seems to be peculiar to man, but the shortness of the spinous process of D 10 (or corresponding vertebra) is also found in many mammals, though not to the same extent. Thus in the galleries of the South Kensington Museum, I found it in the following:

Great cave bear (France)	as regards	D 11
Cervus giganteus	,,	D 12
Brindled gnu	,,	D 12
Okapi	,,	D 10
Clouded leopard	,,	D 11
African rhinoceros	,,	D 15
St Simon (thoroughbred stallion)	,,	D 13

THE MYODOME AND THE TRIGEMINO-FACIALIS CHAMBER IN THE COELACANTHIDAE, RHIZODONTIDAE AND PALAEONISCIDAE

By EDWARD PHELPS ALLIS, Jr.,
Menton, France.

In a recent and excellent work on the *Triassic Fishes from Spitzbergen*, Stensiö (1921) describes what he considers to be the myodome and the trigemino-facialis chamber in certain of the Coelacanthidae and Palaeoniscidae, but his identification of these structures seems to me to be in certain respects incorrect. To properly present my views, the palatoquadrate of these early fishes, as described in the few works I have at my disposal, must first be considered.

Huxley, in 1866, described, in certain of the Coelacanthidae, a great triangular plate of bone which he considered to represent the hyomandibula, quadrate and pterygoid, and he called it the pterygo-suspensorium. The hyomandibula was considered to form the dorsal portion of the somewhat thickened posterior border of the bone, this portion projecting dorsally above the remainder of the bone and having a wide dorsal edge which is said to articulate with a superior process of the prootic, and also with "the roof of the skull." In Macropoma, a process which arises either from the opisthotic or parasphenoid is said to be directed outward from near the base of the skull, and to end "in a free obtuse surface against which the middle of the hyomandibular suspensorium abuts." This process, and a vertical ridge-like process that arises from it, together look so much like the ascending process of the parasphenoid of Polypterus that, in an earlier work (Allis, 1919 *c*), I came to the conclusion that it must represent that process, the trigemino-facialis chamber then lying directly above it, in a depression between it and the dorsal end of the superior process of the prootic of Huxley's descriptions. This conclusion must, however, be wrong, for Stensiö says (1921, p. 62) that the parasphenoid is without ascending processes in all of the Coelacanthidae.

Reis (1888–9), in referring to Huxley's descriptions of these fishes, says that the inclusion of the hyomandibula in the so-called pterygo-suspensorium has been a much contested point, and he himself concludes (*l.c.* p. 18) that that element forms no part of the latter bone. He calls the suspensorium the pterygoid and considers the thickened posterior portion to represent the dorsal half of the mandibular arch, the anteriorly projecting, plate-like portion of the bone having been formed by the fusion with it of dermal, tooth-bearing plates similar to those found in the branchial arches of many fishes. In *Libys*

polypterus, the dorsal end of the thickened hind edge of the bone is shown (*l.c.* Pl. III, fig. 1) apparently articulating with the lateral edge of the posterior portion of the frontal, but in *Macropoma speciosum* it is said to articulate with a dorsal process of the prootic, as Huxley had previously stated to be the case for *Macropoma mantelli*. The dorso-mesial edge of the anterior, plate-like part of the pterygoid is shown, in one of the figures given, articulating with the lateral edge of the parasphenoid. Posterior to the pterygoid, and articulating with the so-called postfrontal and squamosal bones, Reis finds (*l.c.* p. 41) what he considers to be a hyomandibula. There is said to be no epihyal, the ceratohyal being bound to the hyomandibula by ligament, as it is also said by Reis to be in the Sirenidae.

Stensiö, in the work referred to in the opening paragraph of this article, calls the pterygo-suspensorium the palatoquadrate, and says that it contains four independent ossifications, a large dermal one which lies on the internal surface of the apparatus, and three substituent ones which lie external to the dermal one. The dermal ossification he calls the pterygoid and the three substituent ones the quadrate, metapterygoid and palatine. The quadrate and metapterygoid are said to have been quite certainly connected by cartilage, and the metapterygoid is said to articulate, by its dorsal edge, with what Stensiö calls the basipterygoid process of a median basisphenoid bone, this latter bone being the paired prootics of Huxley's and Reis' descriptions. In *Wimania sinuosa* this so-called basipterygoid process apparently extends so far dorsally that it comes into contact with the dermosphenotic portion of the frontodermosphenotic bone, and also closely approaches, if it does not actually reach, the lateral edge of what would seem to be a piscine parieto-pterotic, but is called by Stensiö the parieto-intertemporal. This process of Wimania thus has approximately the position that the corresponding process has in Huxley's figures of Macropoma, but in *Axelia robusta* it is said by Stensiö to extend much less far dorsally.

In *Rhizodopsis sauroides*, Watson and Day (1916) find the "pterygoidal element" articulating, in its orbital portion, with the lateral edge of the parasphenoid, while the vertical posterior portion of the bone "rises to the top of the skull, so as nearly or quite to come into contact with the cranial roof." A quite large hyomandibula is found, and Watson and Day say that it "seems to be extremely feebly ossified, the bone forming a mere skin." It articulates with the otic region of the chondrocranium, near its dorsal edge, and is pierced, just below its head, by a foramen. Traquair (1881) also describes a hyomandibula in this same fish.

From the above references to descriptions of these fossil Crossopterygii, it is evident that the so-called pterygo-suspensorium is simply a palatoquadrate, for both in Libys and Rhizodopsis a hyomandibula has been found lying posterior to it and wholly independent of it. The palatoquadrate of these fishes differs, however, from that in any other known Teleostome in one very important respect, for in addition to having articulation with the lateral edge

of the parasphenoid, it has a posterior and important one with a part of the lateral surface of the neurocranium that would seem to correspond to the postorbital process of recent fishes, notwithstanding that Stensiö says (*l.c.* p. 140) that a real postorbital process is absent in these fishes. This postorbital articulation is considered by Stensiö to be a basipterygoid one, and it is said (*l.c.* p. 126) to be a very old formation, and doubtless a character common to all of the Crossopterygii (*l.c.* p. 71). It is said (*l.c.* p. 71) to correspond essentially to the palatobasal articulation of the Selachii, and each of these articulations is said to probably represent the primary articulation of the mandibular arch with the neurocranium. My work leads me to quite different conclusions, and the relations of the nervus trigeminus and the vena jugularis to the dorsal process of the palatoquadrate and to the so-called basipterygoid process are important in this connection, those of the vena jugularis in particular.

According to Stensiö (*l.c.* pp. 58–60) the ramus ophthalmicus profundus probably issued from the cranial cavity through a canal that traverses the dorsal portion of an anterior process on either side of the median bone that he considers to be a basisphenoid. This anterior process forms the lateral boundary of the fossa hypophyseos, and the external opening of the profundus canal lies ventral to the dorsal end of the basipterygoid process of the basisphenoid, and unquestionably ventral also to the surface of articulation, with that process, of the so-called palatobasal process of the palatoquadrate. The nervi trigeminus and ophthalmicus lateralis are said to issue through an incisure at the base of the posterior edge of the basipterygoid process, and the rami maxillaris and mandibularis trigemini to have presumably passed outward behind that process, or over its posterior part, in a lateral direction. The ophthalmicus lateralis is said to have run forward over the process, close to the lateral wall of the brain case, and the vena jugularis to have had a similar course. This course for the vena jugularis seems wholly improbable for several reasons: first, such an extremely dorsal course would be most exceptional for this vein; second, there is practically no room for its passage dorsal to the basipterygoid process in either Wimania or Macropoma, the dorsal end of the process being, in each of these fishes, practically in contact with the dermal bones of the roof of the skull; and third, as the hyomandibula is evidently of the teleostoman type, the vein must have passed internal to it (Allis, 1915), and to have reached that position after passing dorsal to the so-called basipterygoid process, and hence morphologically external to the articulating process of the palatoquadrate, would require a course so devious and indirect that it is wholly improbable. The vein must accordingly have had a more ventral course and have passed internal to the process of the palatoquadrate. The latter process could not then be a palatobasal one, and if it has its homologue in any process of the palatoquadrate of recent fishes, that process must be either the otic process of the Dipneusti, or the processus muscularis of the Selachii, Holostei and Teleostei; and the wide distribution of the latter process, together with the facts that the process of the Coelacanthidae ossifies as a

piscine metapterygoid bone, as it does in the Holostei and Teleostei, and that it articulates with the cranium in the postorbital region, as in the Notidanidae, instead of fusing with it, as in the Dipneusti, all indicate that it is a processus muscularis, a process frequently, but wrongly, called the otic process. The trigeminus nerves would then all run forward internal to this process instead of outward posterior to it, as Stensiö suggests (*l.c.* p. 70), and this is in accord both with the position of the ophthalmicus profundus as shown by Stensiö himself, and with Huxley's statement that the foramina of the trigeminus nerves lie on either side of the root of his so-called superior process of the prootic, which is Stensiö's basipterygoid process of the basisphenoid. Some part of the space between this process and the cranial wall would then represent either the entire trigemino-facialis chamber, or, as in the Notidanidae, the pars jugularis only, the pars ganglionaris being represented in a recess or cavity in the cranial wall.

In the Palaeoniscidae the conditions are quite different from those above described in the Coelacanthidae and Rhizodontidae. In these fishes the processus muscularis of the palatoquadrate, if present, does not articulate with the neurocranium, and the parasphenoid has ascending processes. In *Birgeria mougeoti* there is, on either side, at the base of the hind edge of the latter process, between it and the lateral edge of the body of the bone, a large foramen which Stensiö (1921, pp. 176–9) says is the posterior opening of a canal which transmits the nervus facialis. He says that it must still be considered an open question whether the root of this nerve, as it issued from the cranial cavity, accompanied the trigeminus roots and so entered the posterior end of a postorbital cavity, described immediately below, or pierced the cranial wall posterior to that cavity; the latter assumption conclusively showing that Stensiö did not consider the canalis facialis and postorbital cavity to be necessarily continuous with each other, or to be primarily in any way related. The postorbital cavity is paired, and is said to presumably correspond to a great extent both to the trigemino-facialis chamber and the myodome of recent fishes, the former chamber lying dorso-lateral to the myodome and the two probably being separated by either membrane or cartilage. The mesial wall of the trigemino-facialis part of the cavity is said to probably correspond to the mesial wall of the pars jugularis of my descriptions of this chamber in the Teleostei, the ascending process of the parasphenoid accordingly forming the external wall of that part of the chamber. The myodome part of the cavity is said to presumably represent a small part only of the dorsal compartment of my descriptions of the myodome of the Teleostei, and it is said to have been invaded not only by the musculus rectus externus, but also more or less by the three other recti muscles. The posterior portion of this so-called myodome forms a longitudinal groove on the posterior portion of the ventro-lateral surface of a sphenoid bone which resembles that of Polypterus but extends somewhat farther posteriorly. The grooves of opposite sides are separated from each other by what Stensiö calls the parachordal portion of

the sphenoid bone, and the anterior ends of the grooves are connected by a cross-canal which traverses the postero-ventral end of the pituitary fossa and is called by Stensiö the canalis transversus. A longitudinal slit in the roof of the groove is said to have probably given passage to the nervus abducens (*l.c.* p. 170). This groove, or so-called myodome, is said (*l.c.* p. 166) to have been closed posteriorly partly by the parachordal plate and partly by cartilage that forms the anterior portion of the labyrinth region. No connection whatever with the canalis facialis is suggested. The widely separated myodomic cavities of opposite sides are assumed to have gradually approached each other and finally fused to form the median myodome of modern fishes, the conditions in the Palaeoniscidae thus representing a very primitive phylogenetic condition.

With these interpretations of the conditions in these fishes, so fully and excellently described by Stensiö, my work leads me to disagree, and here, as with the Crossopterygii, it is the course of the vena jugularis that is of prime importance. According to Stensiö (*l.c.* p. 178), this vein, running posteriorly, probably entered the anterior end of the so-called myodomic part of the post-orbital cavity, but soon turned upward into the trigemino-facialis part, the latter part of the cavity lying between the ascending process of the parasphenoid and the lateral wall of the sphenoid and, as already stated, being considered by Stensiö to correspond to the pars jugularis of the trigemino-facialis chamber of the Teleostei. The further course of the vein is not given, but as the so-called trigemino-facialis chamber has no posterior opening, the vein must, in Stensiö's opinion, either have run posteriorly external to the ascending process of the parasphenoid, or have entered the cranial cavity through the foramen trigeminum. The latter one of these two assumptions seems wholly improbable; and if the vein passed external to the ascending process, the latter process would necessarily be similar to that in Cottus and Amiurus and would correspond to the inner wall of the pars jugularis of the trigemino-facialis chamber of other fishes (Allis, 1909, 1919 *a*), instead of to its external wall, which is in itself improbable and is furthermore contrary to the homology proposed by Stensiö himself. The vein must accordingly have passed internal to the ascending process, and this assumption is confirmed by a comparison with the conditions in Polyodon, a fish much more closely related to the Palaeoniscidae than either Cottus or Amiurus. In Polyodon the vena jugularis (Allis, 1911, p. 291) traverses a canal in the cranial wall that Bridge (1879) described as the facial canal. The nervus facialis issues from the posterior opening of this canal, accompanied by the vena jugularis, and before entering the canal the latter vein receives a branch from the pituitary body. The ganglion of the nervus trigeminus lies largely within the cranial cavity, and the several branches of the nerve pierce the cranial wall slightly anterior to the anterior opening of the facial canal. These conditions in this fish thus so closely resemble those described by Stensiö in Birgeria that it seems practically certain that the so-called myodomic groove, or fossa, of

the latter fish is simply a part of a jugular canal similar to the facialis canal of Polyodon. The conditions in the two fishes are then strictly comparable, the so-called myodome of Birgeria becomes the canalis facialis of Polyodon, and there is no functional myodome in either of these fishes.

LITERATURE CITED

Allis, E. P. Jr. (1909). "The Cranial Anatomy of the Mail-cheeked Fishes." *Zoologica*, Bd. 22. Stuttgart.

—— (1911). "The Pseudobranchial and Carotid Arteries in *Polyodon spathula*." *Anat. Anz.* Bd. 39. Jena.

—— (1915). "The Homologies of the Hyomandibula of the Gnathostome Fishes." *Journ. Morphol.* vol. 26. Philadelphia.

—— (1918). "On the Origin of the Hyomandibula of the Teleostomi." *Anat. Rec.* vol. 15. Philadelphia.

—— (1919 *a*). "The Myodome and Trigemino-facialis Chamber of Fishes and the corresponding Cavities in higher Vertebrates." *Journ. Morphol.* vol. 32. Philadelphia.

—— (1919 *b*). "On the Homologies of the Auditory Ossicles and the Chorda Tympani." *Journ. Anat.* vol. 53. Cambridge.

—— (1919 *c*). "The Homologies of the Maxillary and Vomer Bones of Polypterus." *Amer. Journ. Anat.* vol. 25. Philadelphia.

Bridge, T. W. (1879). "Osteology of *Polyodon folium*." *Phil. Trans.* vol. 169. London.

Huxley, T. H. (1866). "British Fossils. Illustrations of the Structure of the Crossopterygian Ganoids." *Mem. Geol. Survey of the United Kingdom.* Decade XII, Scientific Memoirs.

Kindred, J. E. (1919). "The Skull of Amiurus." *Illinois Biological Monographs.* vol. 5.

Pollard, H. B. (1894). "Suspension of the Jaw in Fishes." *Anat. Anz.* vol. 10. Jena.

Reis, O. M. (1888–9). "Die Coelacanthinen mit besonderer Berücksichtigung der im Weissen Jura Bayerns vorkommenden Arten." *Palaeontografica.* Bd. 35. Stuttgart.

Stensiö, Erik A:son (1921). *Triassic Fishes from Spitzbergen.* Vienna.

Traquair, R. H. (1881). "On the Cranial Osteology of Rhizodopsis." *Trans. Roy. Soc.* vol. 30. Edinburgh.

Watson, D. M. S. and Day, H. (1916). "Notes on some Paleozoic Fishes." *Mem. and Proc. Manchester Lit. and Phil. Soc.* Session 1915–16.

A HUMAN FOETUS EXHIBITING INIENCEPHALY AND OTHER ABNORMALITIES

By WILLIAM IVON HAYES, M.B. (Melbourne),

Trinity College, Dublin.

Through the kindness of the Master of the Rotunda Hospital, Dublin, I was permitted to examine the unusual foetus here described. I am unable to find any previous record of a similar foetus having occurred in the practice of the hospital, and certainly none such has been seen there within the last ten years.

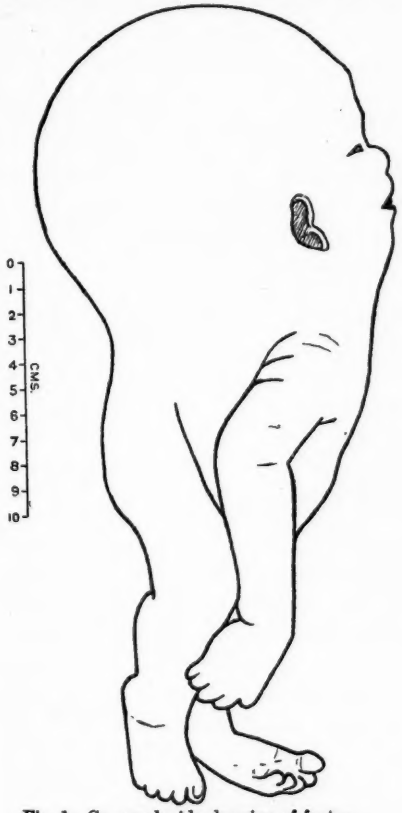


Fig. 1. Camera lucida drawing of foetus, from right side.

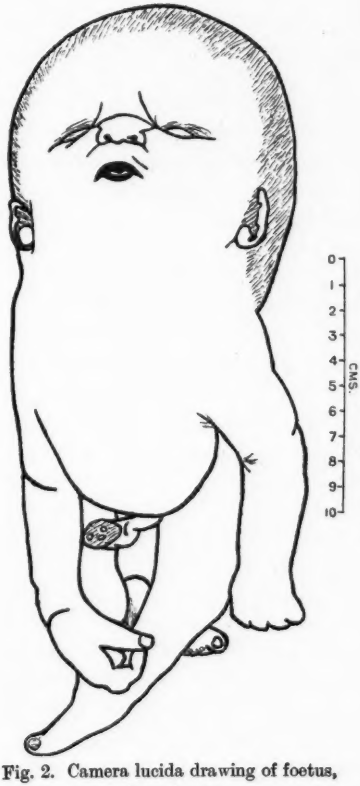


Fig. 2. Camera lucida drawing of foetus, from front.

The foetus is full time. The hair is about half an inch long on the head, the nails project just beyond the finger tips and unusually large centres of ossification are present at the lower end of the femur, and the upper end of the tibia.

The head is slightly enlarged, measuring 38 cms. in greatest circumference, and the face looks slightly upwards. Owing to the increase in size of the vault of the skull, the ears, which are both somewhat deformed, seem to be set more anteriorly than normal. The head is imperfectly separated from the body by an ill-defined neck, so that the contour of the head is almost directly continuous with that of the body. The abdomen is protuberant, with the umbilicus looking downwards, while the back, between the occiput and the nates, is greatly decreased in length. The combined length of the head and body is 23 cms., while the length of the entire foetus measures 38 cms. There is no external sign of any protrusion of the contents of the spinal canal, and the integument of the occiput passes uninterruptedly down over the back and sacrum. Owing to the shortness of the back, the lower limbs are attached dorsally, while the arms are attached ventrally and only slightly above them, so that the fingers reach down almost to the feet.

On mesial sagittal section, it is at once seen that the deformity is due to malformation of the cranio-vertebral axis, which is much shortened, and forms practically a straight line from the nasal septum to the sacrum. The viscera are consequently pushed downwards and forwards. On the left side a pseudo-hernia is present, part of the liver and some intestines passing through the diaphragm into the left pleural cavity, where they lie lateral to the left lung. The herniated viscera are not enclosed in a peritoneal hernial sac. Owing to the presence of this hernia, the pericardium and the heart lie wholly on the right side of the medial plane. The various viscera appear normal. The thymus is almost spherical and is placed in the neck just above the sternum. The internal genitals, which are female, are well developed. The suprarenals and the pituitary were both examined microscopically, and were found to be normal.

The cranio-vertebral axis, passing from the anterior end of the nasal septum to the last piece of the sacrum measures 16 cms. and forms practically a straight line, except for a short anterior convexity at about its middle. At its cephalic end can be distinguished the mesethmoid, presphenoid, basi-sphenoid, basi-occipital, and the cartilaginous anterior arch of the first cervical vertebra. More caudally, in the region of the anterior convexity, there is a mass, in which there are a number of irregular malformed centres of ossification. Here the different vertebrae are indistinguishable. Following this irregular mass, may be seen a number of well formed vertebræ, and the 11th thoracic to the 5th sacral may be distinguished. The 5th lumbar vertebra is partly fused with the first sacral. The reduction in length of the vertebral column is thus due to an irregular fusion, or, more correctly, a failure in separation of the cervical and thoracic vertebrae. The vertebral neural arches are all deficient, none of them uniting posterior to the spinal cord.

The foramen magnum is of large size, measuring 6 cms. antero-posteriorly. It is formed in front by the basi-occipital, and laterally by the ex-occipitals, to which are united the neural arches of the fused vertebrae. Posteriorly the

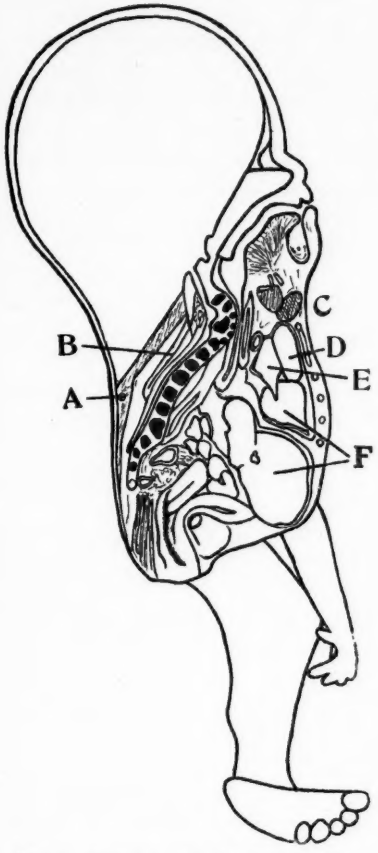


Fig. 3. Median section showing left side.
A, supra-occipital; B, spinal cord; C, thymus; D, intestine; E, lung; F, liver.

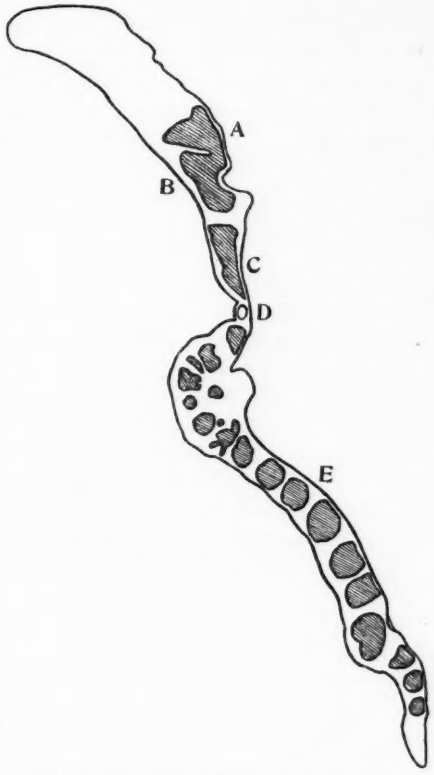


Fig. 4. Section of Cranio-vertebral Axis, from left side.
A, presphenoid; B, basi-sphenoid; C, basi-occipital; D, anterior arch of atlas; E, first lumbar vertebra.
Owing to the section not being exactly mesial, the centre of ossification of the 5th sacral vertebra is not seen.

foramen is completed by the supra-occipitals, which are united behind the spinal cord, opposite the 4th lumbar vertebra. Caudal to this, the remainder of the vertebral canal is covered by the meninges and integument alone. The

inter-parietal part of the occipital bone is unossified, but the other membrane bones of the skull are well developed.

The ribs, which are eleven in number on each side, are, in their dorsal parts, fused to one another, and to the vertebrae from which they arise.

The central nervous system was much injured during delivery. There is a mass of nervous tissue, representing the pons and cerebellum, beneath the tentorium cerebelli. Its different parts cannot, however, be distinguished. From this mass a spinal cord runs downwards to the level of the third sacral vertebra.

The cranial nerves are normal, in number and plan. All the spinal nerves are present, and the great plexuses are normal in their constituents and mode of formation, except that the lowest trunk of the brachial plexus is formed by the union of the division of the 8th cervical nerve, the whole of the first thoracic and the greater part of the second thoracic nerves. The remainder of the 2nd thoracic nerve formed the nerve of the first intercostal space, and the succeeding thoracic nerves are each anteposed one space, the 12th thoracic nerve lying below the last, or 11th, rib.

The musculature appeared normal, but the dorsal muscles are very thin.

The more interesting points of the specimen are:

1. The absence of the neck.
2. The condition of hydrocephalus.
3. The deformity of the vertebral column.
4. The unclosed vertebral neural arches.
5. The large size and the formation of the foramen magnum.
6. The diaphragmatic hernia.

Following the classification of Ballantyne (1), the above points would lead us to place the monster in the class, iniencephaly. The cardinal characteristics of this type, are a backward bending of the vertebral column with a varying degree of spina bifida, and imperfect formation of the occiput in the region of the foramen magnum. In most cases it is usual to meet with an occipital encephalocele, or a spina bifida with a protrusion of the spinal meninges. Schwalbe (2) would classify the condition under the term Rachischisis. He finds that it is very rare to have all the vertebral neural arches ununited, and that the commoner type is accompanied by a cleavage of the occipital region of the skull. Schwalbe also lays stress on the very interesting feature of the ex-occipitals being fused with the vertebrae. The foetus under examination exhibits this latter condition very well, and also has the rarity of a complete vertebral cleavage with an uncleft occiput. Wheeler (3) describes in detail a most interesting iniencephalic foetus, but her case appears to be of the more common type, and presents a well marked encephalocele.

The condition of iniencephaly is uncommon, nevertheless, Ballantyne had met with seven cases up to the year 1904. The sex is apparently usually female (4).

The etiology is not quite clear. The malformation of the spine is apparently

the primary condition, and the closure of the vertebral arches appears to be prevented by the dorsal displacement of the occiput. The absence of the neck is directly due to the shortening of the spinal column, and the diaphragmatic hernia probably results from the same cause. The malformation of the spine may be due, either to the pressure of the amniotic fluid, or where that is deficient, to the pressure of the uterus itself. More probably it is due to a malformation of the foetus, and not the result of external pressure.

Quite recently Stockard (5), by experimental methods, has shown that most monsters are caused by arrests in development. If we assume that iniencephaly is also due to an arrest, we must look for an embryonic stage in which there is a dorsal concavity of the vertebral axis. Such a stage is represented by His' embryo 3·2 mm., aged about 3 weeks. Inasmuch as embryos with this dorsal thoracic concavity are themselves regarded as abnormal, we can readily understand that, if iniencephaly is the result of an arrest in this stage, it must of necessity occur but rarely.

REFERENCES

(1) Ballantyne, J. W. *Antenatal Pathology and Hygiene.*
(2) Schwalbe. *Die Morphologie der Missbildungen des Menschen und der Tiere* (III. Teil, 1. Lieferung, 1909).
(3) Wheeler, Theodora. "Study of a human spina bifida monster with Encephaloceles and other abnormalities." Contributions to Embryology, No. 22. *Public. Carnegie Instit. Wash.* 227, pp. 87–110.
(4) Lewis, H. F. *Amer. Journ. Obstet.* xxxv, 11, 1897.
(5) Stockard, Charles. "Developmental and Structural Expression, etc." *Amer. Journ. Anat.* vol. 28, No. 2. Jan. 1921.

REVIEWS

Studies in the Palaeopathology of Egypt. By Sir MARC ARMAND RUFFER, C.M.G., M.D., Late President of the Quarantine Council of Egypt. Edited by ROY L. MOODIE, PH.D., Associate Professor of Anatomy in the University of Illinois. pp. 372. Plates LXXI. (Chicago University Press.)

This stately volume contains studies by the late Sir Marc A. Ruffer on the diseases of historic and prehistoric peoples—a branch of medical knowledge to which he gave the name of Palaeopathology. In an introductory note to the eighteenth study or paper of the series contained in this volume, Lady Ruffer writes as follows: "When starting in December, 1916, on a mission which was evidently attended by dangers and which finally proved fatal to my husband, he left with me instructions as to the various unfinished papers at which he and I had worked together."

To say that a voyage across the Mediterranean from Egypt to Salonika in the winter 1916–1917 was attended with "dangers" is an inadequate expression of the murderous success which then attended the submarine campaign. Ruffer, having given his medical aid in Salonika was torpedoed on his way back to Egypt and gave his own life to save that of a fellow passenger. He was then 57 years of age, 20 of which he had spent in Egypt as pathologist and as President of the Sanitary Council. He was one of the first British pupils of Pasteur and Metchnikoff. He was a master of microscopical technique which he applied to the investigation of the tissues and diseases of ancient Egyptians. These studies occupied intervals stolen from his official duties.

The papers deal with the histology of Egyptian mummies; a case of spinal caries of 1000 B.C., the detection of *Bilharzia haematobia* in mummified kidneys, arterial lesions, skin eruption resembling variola, dwarfs and deformed persons found in ancient tombs or records. The chief papers deal with chronic arthritis and diseases of the teeth and jaws.

This memorial volume has many interests for anatomists for the examination of ancient human remains usually falls to their province. Sir Marc A. Ruffer, almost in every page, acknowledges his indebtedness to Professor Elliot Smith and Professor Wood Jones, who made the *Reports of the Archaeological Survey of Nubia* a mine of wealth for pathologists as well as for anthropologists and anatomists for many years to come. Further, the volume has been ably edited by an anatomist, Professor Roy L. Moodie. The volume forms a fitting remembrance of a handsome, gallant, engaging and gifted personality.

New German Text-book of Human Anatomy.

Anatomie des Menschen: ein Lehrbuch für Studierende und Ärzte. Von Hermann Braus, Professor an der Universität, Direktor der Anatomie, Heidelberg. Erster Band, Bewegungsapparat. pp. 835. Figs. 400 (mostly in colour). (Berlin, Julius Springer.) 1921. Price not stated.

The appearance of this work is evidence that a revolution is taking place in the outlook of teachers of human anatomy in Germany. Its prototype is to be sought for in the *Handbuch der Topographischen Anatomie* of Professor Merkel rather than in the great *Handbuch der Anatomie des Menschen* edited by the late Professor Karl von Bardeleben. In its conception, execution and arrangement, this new work differs from both of these. Merkel and Bardeleben, in their several ways, designed their books to serve as encyclopaedias to meet the needs of professional anatomists; for the progress of anatomy the publication of such books is absolutely essential. These great modern text-books are framed on too large a scale for the education of young men who are to spend their lives in studying the living human body in health and its treatment in disease. Dr Braus, the Professor of Anatomy in the University of Heidelberg, regards the needs of the medical student and practitioner as identical and has framed his text-book to meet their common needs. Instead of displaying the human body to the student in topographical regions or in structural systems he seeks to present it as a working whole. He has brought to bear in his presentation all modern sources of knowledge; well modelled drawings and photographs of the living body, and of its various parts in action, help the student to translate his dead dissections into live anatomy; he has drawn freely on radiology to illustrate his text. Comparative anatomy and embryology are made to illuminate the origin and nature of structural arrangements. Microscopical anatomy is interwoven with descriptive anatomy. The illustrations are numerous and of high finish. Above all, form is studied to throw light on function; his chief aim is to emphasise the use rather than the form of parts.

Alas! the book has no index; only an elaborate table of contents. The opening chapter gives an account of the size, form of the body and of the structural elements which make up its component parts. The author then passes on to consider the structure and origin of the tissues concerned in the movements of the body. The vertebral column and its muscles are the first regional parts to be dealt with; the musculature of the trunk is treated as a whole which is as it should be, for in their action the various muscles of the trunk make a single complex. A description of the origin, form and mechanism of the skeletal parts and muscles of the limbs and of the head complete the present volume.

Anatomy is here presented as a single-author survey; authorities are rarely quoted; references to original papers or recent literature are seldom made; the author places before the reader what he believes, in the light of

twenty years of teaching, will prove most useful in the pursuit of medicine. Although the manner in which muscles carry out the action of the body is dealt with at great length yet there is a lack of perspective in the method of treatment. When we seek to obtain a working picture from the author's text of how the vertebrae are kept balanced one upon the other in the standing or sitting posture, or of the movement of ribs and action of muscles in quiet respiration or the part played by muscles in maintaining the arch of the foot, we find it hard to come by. There is a prolixity, as well as a force, in the author's style. It is clear, too, that this text-book, when completed, will be too bulky to serve as a manual for the ordinary student of medicine.

Hereditary Disease. By HERMANN W. SIEMENS. "Einführung in die allgemeine Konstitutions- und Vererbungspathologie." pp. 229 + vii. Julius Springer. Berlin, 1921.

Professor Siemens states in the introduction to his book that his aim has been to select from the literature on the subject of Heredity those parts which have a medical interest and which bear on the problems of hereditary diseases. This he has accomplished in a work, compact and clearly written, and neither submerged in complex abstractions nor overburdened with an abstruse technical terminology.

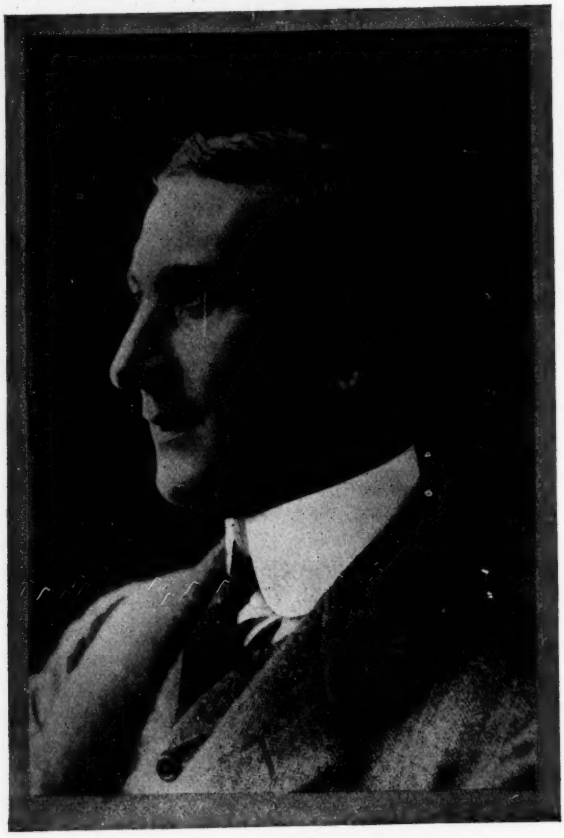
In the first, the theoretical, part, the author deals with the broad general conceptions of the endogenous factors in disease, and defines with considerable clearness the scope of such terms as "malformations," "anomalies," "constitutional disease" and "hereditary predisposition." A short description of Mendelian principles is given, and this is followed by an analysis of the cytological bases of hereditary transmission. The chromosome theory and its corollary, the purity of the gametes in respect of their qualities as attained in maturation, are accepted, while the problems of the determination of sex are held to be solved in the heterochromosomes—full notice being given to the non-correspondence of the sex-proportion of births and the distribution of the *X* and *Y* bodies; and the author's conclusion in this respect, therefore, is, "eine willkürliche Bestimmung des Geschlechtes beim Menschen erscheint wohl für ewig unmöglich." In the second, the practical, part of the work, the usual methods of investigation are described, and an extensive critical analysis is then made of the actual findings in transmitted disease and a comparison instituted with the postulates of the Mendelian laws. This is the longest part of the book, and with full tables of an interesting group of conditions—many of them personal observations—discussed from many points of view, the close correspondence of transmitted disease, as dominants or recessives, to the theoretical requirements is established. There is an interesting inquiry into the meaning of hereditary disease, centred round the question as to whether the anlage of disease may be established through external factors, alcoholism for example, becoming influences which may act on the germ plasm and be causative of idioplasmic variation. A chapter on the possible method of control

and elimination of hereditary disease, scientifically orthodox but put forward in a manner not over dogmatic, concludes the book, apart from an appendix on a tentative classification of hereditary diseases, a glossary of the biological terms used in works on Heredity, and a bibliography of the more important works on the subject.

The book forms an admirable introduction to the study of hereditary diseases, and its wide scope and the suggestive manner in which it is written should make it a distinct stimulus to further inquiry.

OBITUARY NOTICE

DR PETER THOMPSON, Professor of Anatomy in the University of Birmingham, died at Penmaenmawr, after a long illness, on Nov. 16th, 1921.



Professor PETER THOMPSON

He studied medicine at Owens College, Manchester, and graduated, in 1894, when he was 22 years old, as M.B., Ch.B., in the Victoria University.

In the following year he was appointed junior demonstrator of Anatomy in the Victoria University and shortly afterwards became senior demonstrator and lecturer.

In 1901 he was elected to the Lectureship in Anatomy in the Medical

School of the Middlesex Hospital, London, and obtained thereby the full control of a department.

Four years later, in 1905, he became Professor of Anatomy in King's College, London, and in 1909 was transferred to his last anatomical post, the Professorship of Anatomy in the University of Birmingham.

The son of a successful Lancashire business man he inherited business capabilities which, combined with an abundant enthusiasm, account for much of his success.

As concerns Anatomy it accounts for the detailed thoroughness of his work, and for the fact that he extracted the utmost amount of information from every specimen that fell into his hands. It also accounts for his cautious estimation of the value of results and for his restrained judgment concerning the probable line of research which the results might suggest.

The influence is still more markedly illustrated by his success as a manager and organiser, not only as the head of an anatomical department, but also as an officer in the Victoria University Volunteer Corps; as Secretary, Vice-President, and President of anatomical sections of British Medical Association Meetings; as Secretary, Treasurer and Vice-President of the Anatomical Society; and as Dean of the Medical Faculty both at King's College, London, and at Birmingham.

He was essentially a social person, always anxious and glad to take part in the organisation of meetings, either for the promotion of social pleasure or for the advancement of knowledge, and the occurrence and success of many important meetings were due to his initiative, his tireless efforts and his intense energy.

He was a fluent, lucid and impressive speaker, who possessed the invaluable capability of grasping and carrying with him the interest of his audience, whilst, at the same time, he impressed upon it the importance of the subject dealt with.

His purely anatomical work was morphological and embryological.

In the earlier period, when he was at Manchester, he investigated the structure and morphology of the pelvic floor and illuminated his results with questions of medical and surgical importance.

In London he became interested in the embryological aspect of morphology and his subsequent publications were mainly descriptions and discussions of reconstructions of embryos, which threw considerable light on many phases of development previously obscure, and which brought into prominence facts not previously noted.

He was, however, much more than an anatomist, an organiser and a teacher, he was a stimulating lovable man, willing to offer and share pleasures, always ready to help, encourage and sympathise, and his death has deprived many of us not only of a pleasant colleague but also of a faithful and invaluable friend.

ARTHUR ROBINSON.